UTAH DEPARTMENT of ENVIRONMENTAL QUALITY
WATER QUALITY

Utah Lake Water Quality Study

Phase 1 Report

Final –December 7, 2018

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1 Executive Summary

This report summarizes Phase 1 of the Utah Lake Water Quality Study (ULWQS) work plan, initiated in November 2015. The work plan established 5 work elements to set the foundation for data collection and analytical tools needed for developing nutrient criteria for Utah Lake to protect the recreation, aquatic life, and agricultural beneficial uses of the lake. The five work plan elements include: 1) stakeholder development and outreach; 2) data coordination and management; 3) beneficial use assessments; 4) nutrient load analysis; and 5) model development. This report summarizes the work completed and data associated with each task.

The scope of the Phase 1 effort changed considerably from the start of the project as a result of highly interested and engaged stakeholders and the significant interest by the local research community in studying Utah Lake. This interest led to a reorganization of the stakeholder structure and development of a more formalized approach. Phase 2 of the study is being led by a representative interest-based Steering Committee and an expertise-based Science Panel, who will work together to develop scientifically defensible nutrient nitrogen and phosphorus criteria for the lake. It is envisioned that Phase 2 will continue through 2020. The implementation phase, Phase 3, will begin in 2020 and continue through the implementation of any recommended water quality criteria into permits in 2030.

This report focuses discussion on the 5 work plan elements developed in November 2015, the work accomplished with each, recommendations for improvements, and their application in Phase 2. The layout of this report follows the work plan elements closely with each section briefly summarized here:

1.1 Task 1 – Stakeholder Involvement (Section 3)

The stakeholder involvement section discusses the formulation of the original stakeholder group in 2015 and the development of the ULWQS Stakeholder Process document that establishes the Steering Committee and Science Panel.

1.2 Task 2 – Data Management and Compilation (Sections 4 and 5)

DWQ led an active work group in 2015 and 2016 with the intent of coordinating a multi-organization monitoring effort. This section also discusses compilation of available data resources and development of a database to be shared with all project partners. Additionally, the Utah Lake Data Explorer, a tool developed to help visualize temporal and spatial trends in the Utah Lake dataset, is presented in Section 5.

1.3 Task 3- Water Quality Assessment and Analysis (Section 6)

The Water Quality Assessment and Analysis section presents and updated beneficial use assessment to include Utah Lake data collected in 2015 and 2016. This section also includes an analysis of common trophic state variables.

1.4 Task 4 – Source and Nutrient Load Analysis (Sections 8 and 9)

The Utah Lake Loading Analysis section presents available water and nutrient budgets for the lake and discusses ongoing data collection efforts to improve these estimates through ongoing watershed modeling efforts. Additionally, section 9 discusses information related to a future watershed source allocation effort planned for Phase 3 of the ULWQS.

1.5 Task 5 – Model Selection and Development (Section 7)

Section 7 discusses the DWQ model selection effort and integration with the University of Utah modeling project.

2 Introduction

2.1 *Beneficial Uses and Water Quality Impairments*

Utah Lake is listed on the State of Utah's 2016 303(d) with impairments to the aquatic life (3A) and infrequent primary contact recreation (2B) uses. Designated uses for Utah Lake are presented in Table 1. Table 2 summarizes the 303(d) impairments for each designated use and the year that the impairment was added to the 303(d) list. The most recent 2016 Integrated Report (DWQ, 2016) resulted in listings for Harmful Algal Blooms (HABs) in the open water of Utah Lake for the recreation use and impairments to the aquatic life use in Provo Bay due to exceedances of ammonia standards and elevated pH values (Table 2).

Table 1. Utah Lake Designated Beneficial Uses.

Classification	Description of Beneficial Use
2B – Recreation and Aesthetics	Protected for infrequent primary contact recreation. Also protected for secondary contact recreation where there is a low likelihood of ingestion of water or a low degree of bodily contact with the water. Examples include, but are not limited to, wading, hunting, and fishing.
3B – Aquatic Wildlife	Warm water species of game fish and other warm water aquatic life, including the necessary aquatic organisms in their food chain.
3D – Aquatic Wildlife	Waterfowl, shore birds and other water-oriented wildlife not included in Classes 3A, 3B, or 3C, including the necessary aquatic organisms in their food chain
4 –Agriculture	Protected for agricultural uses including irrigation of crops and stock watering

Table 2. Utah Lake 303(d) List Impairments.

Year Listed	Water Body	Parameter	Use Impaired
2002	Utah Lake	Total Dissolved Solids	4 – Agricultural
2002	Utah Lake	Total Phosphorus	3B - Aquatic Life
2010	Utah Lake	PCBs	3B - Aquatic Life
2016	Utah Lake	Harmful algal bloom	2B - Recreational
2016	Provo Bay	Ammonia	3B – Aquatic Life
2016	Provo Bay	pH	3B – Aquatic Life

2.2 *Utah Lake Water Quality Study (ULWQS)*

The Utah Division of Water Quality (DWQ) initiated a water quality study in November 2015 to evaluate the effects of nutrient enrichment on Utah Lake's beneficial uses. Phase 1 of the study focused on the compilation and synthesis of existing water quality and related information. Phase 2 of the study will develop in-lake water quality criteria necessary to restore and protect Utah Lake's designated recreational, aquatic life, and agricultural uses. The specific focus for this study is the development of appropriate site-specific criteria for nitrogen and phosphorus to reduce the occurrence and severity of undesirable aquatic life such as harmful algal blooms.

The *Utah Lake Water Quality Work Plan 2015 -2019* (DWQ, 2015) was developed in 2015 to guide Phase 1 of the study and presented five work plan tasks:

- Task 1 - Stakeholder Outreach and Public Involvement
- Task 2 - Data and Information Management
- Task 3 – Beneficial Use Assessment
- Task 4 – Source and Nutrient Load Analysis
- Task 5 – Model Development

The work plan approach has changed in response to a number of discussions with stakeholders, recent HAB events, and ongoing Utah Lake studies at local universities. The most notable is the University of Utah study assessing the impacts of climate change and urbanization on water quality in the Jordan River watershed. This study is developing water quality models that will be applied to determine nutrient criteria for the lake. These changes have resulted in adjustments to timing of the study work elements, a revision of the stakeholder process, the methods employed for data collection, how source loads are calculated, and development and implementation of water quality models for the lake. This report presents the results and current status of each work plan task.

3 Stakeholder Involvement

Outreach efforts outlined for Phase 1 were intended to ensure a collaborative process with engaged stakeholders to guide scientific analyses and regulatory decision making. The stakeholder group assembled in 2015 was comprised mostly of members of the Utah Lake Commission Technical Committee with representatives from the Utah Lake Commission (the Commission), local municipalities, publicly-owned treatment works (POTWs), water users, and state and local agencies. Additional stakeholders were invited to represent agricultural and recreational interests along with local university researchers actively studying Utah Lake.

Four water quality subgroups were formed from the larger stakeholder group to address the technical and scientific questions associated with each Phase 1 work element. These subgroups focused on data management and coordination of monitoring efforts and model development.

3.1 Revised Stakeholder Process

Working with the existing stakeholder group, DWQ and the Utah Lake Commission revised the approach to accommodate a rapidly growing stakeholder group and to provide a formal process to more effectively incorporate all stakeholder concerns in the process. The resulting Utah Lake Water Quality Study *Stakeholder Process* (DWQ, 2017) presents a charter for accommodating the current and evolving stakeholder landscape.

The new process establishes a Steering Committee and a Science Panel, charged with gaining broad acceptance of the process and outcomes through a consensus based, transparent, and scientifically defensible approach. Figure 1 presents a diagram showing general interactions of these committees and their responsibilities and objectives with additional discussion presented in the following sections.

3.1.1 Steering Committee

The Steering Committee is structured as an interest-based group with representatives from stakeholders with an interest in the Utah Lake Water Quality Study. Members of the Steering Committee (Table 3) are responsible for representing interests of their respective constituents and to guide and develop scientifically defensible water quality regulations and policies protective of Utah Lake's designated uses.

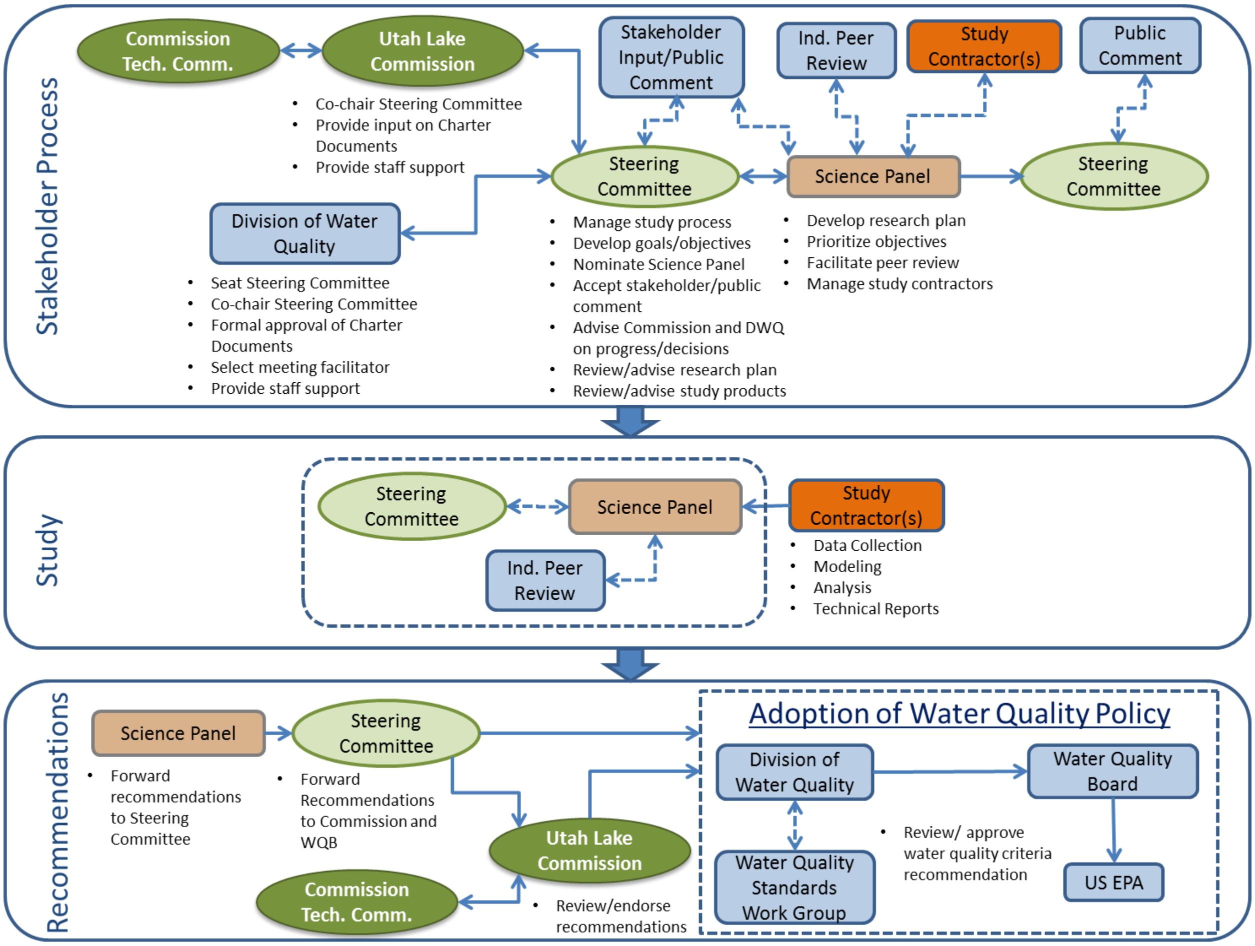


Figure 1. Stakeholder Process Diagram.

Objectives for the Steering Committee include:

- Create a partnership among stakeholders
- Conduct a transparent public process
- Develop goals and objectives for the Utah Lake Water Quality study
- Establish, maintain, and direct a Science Panel
- Provide recommendations for water quality criteria to the Utah Water Quality Board

Table 3. Utah Lake Steering Committee Interest and Affiliation.

Stakeholder Interest	Affiliation
Utah Lake Commission (Co-chair)	Utah Lake Commission Executive Director
Water quality (Co-chair)	Utah Division of Water Quality
Recreation, fishing, and sovereign lands	Utah Department of Natural Resources
Agriculture/ water rights/ water users	Utah Lake Water Users Association
Fish and wildlife	U.S. Fish and Wildlife Service
Agriculture	Utah Conservation Commission Zone 3, Utah Department of Agriculture and Food, or local agricultural interest
Public health	Utah County Health Department
Recreation	Recreational club, anglers, hunters, or business
Conservation and environment	Environment or conservation organization
Water management of Utah Lake	Central Utah Water Conservancy District or appropriate water manager
Stormwater	Utah County
Publically Owned Treatment Works	Municipal or special service district
Municipal	City Mayor or designee
Municipal	City Mayor or designee
Municipal	City Mayor or designee
Academia	University researcher

3.1.2 Science Panel

The Science Panel, in contrast to the Steering Committee, is a disciplinary-based panel with members having scientific expertise relevant to Utah Lake. Objectives and duties of the Science Panel include:

- Develop a scientifically defensible approach for the study
- Identify gaps in scientific understanding and data
- Provide recommendations to the Steering Committee for scientific study
- Oversee Utah Lake research activities
- Implement a process for independent peer review
- Develop a process to characterize scientific uncertainty

The Science Panel membership is structured a two-part panel including 5 independent voting members and 5 ex officio non-voting members. This structure was determined by the Steering Committee with an expectation that members are independent from any member of the Steering Committee or their organization, but also to provide a mechanism to include local scientists with Utah Lake expertise in the process. The Science Panel membership is shown in Table 4.

Table 4. Utah Lake Science Panel Membership and Expertise.

				Related Expertise										
	Representative	Affiliation	Primary Discipline	Aquatic ecology	Biogeochemistry	Fisheries management	Hydrodynamic modeling/hydrology	Nutrient cycling	Limnology	Phycology	Toxicology	Water quality criteria	Water quality modeling	Wetland science
Independent (Voting)	Michael Brett	University of Washington	Limnology						X					
	Mitch Hogsett	Forsgren Associates	Biogeochemistry		X									
	Ryan King	Baylor University	Aquatic ecology	X	X			X	X				X	X
	James Martin	Mississippi State University	Water quality modeling	X	X		X	X				X	X	
	Hans Paerl	University of North Carolina	Limnology	X	X			X	X	X				
Ex Officio (Non-Voting)	Janice Brahney	Utah State University	Biogeochemistry		X									
	Soren Brothers	Utah State University	Limnology						X					
	Greg Carling	Brigham Young University	Biogeochemistry		X			X						
	Jereme Gaeta	Utah State University	Aquatic ecology	X		X								
	Theron Miller	Wasatch Front Water Quality Council	Biogeochemistry	X	X	X	X	X	X		X	X	X	X

3.1.3 Stakeholder Facilitation

The *Utah Lake Water Quality Study Stakeholder Process* document recommended that all Steering Committee and Science Panel meetings be conducted by an independent professional facilitator. DWQ contracted with RESOLVE, a professional facilitation team, in November 2017 to guide the stakeholder process. Facilitation activities with the project include developing a preliminary situation assessment to gage stakeholder interest, identify areas of mutual gain, and stakeholder expectations for the study. The team is also responsible for facilitating all Steering Committee and Science Panel meetings including agenda development and meeting planning and developing meeting action items to inform the next steps.

The facilitation team is also developing a recommended approach for public engagement that will serve as a tool for Steering Committee members to use for informing and engaging the public throughout the study.

4 Data Management and Compilation

4.1 Data Acquisition and Compilation

During a stakeholder meeting in November, 2015, DWQ emphasized the importance of compiling all available data and housing it at DWQ. Group representatives, research groups and future investigators were asked if they were planning to conduct studies on Utah Lake during the period 2016-2019. As a result, a list of potential primary investigators was formulated. The DWQ also explained to the attendees that compiling and housing all the data at DWQ would provide a more holistic approach during the data analysis phase. To target this objective, DWQ held several meetings with the potential primary investigators (February 2016, October 2016, May 2017) providing information of the data types already available to the DWQ and the types of data the DWQ expects each primary investigator to compile and submit to the DWQ. When a research group or potential primary investigator could not attend one of these meetings, DWQ personnel met with them at a date convenient for them to communicate and update them on the meeting agenda and decisions made. During these meetings, DWQ also shared details about their:

- sampling efforts
- sampling frequencies
- site list(s)
- parameter list(s)
- lab allocation / capacity
- Sampling Analysis Plan (SAP)

4.2 Utah Lake Monitoring Plan

The majority of DWQ's resources are dedicated to collecting environmental samples (data) that describe the conditions of Utah Lake (open water sites) and tributary sites (major tributaries) to Utah Lake. This data will be critical in benchmarking current conditions and understanding what additional studies might be required to meet the objectives of the Utah Lake study.

To meet this objective, the DWQ developed a SAP to address two primary goals to support the Utah Lake Water Quality study and to support DWQ's harmful algal bloom (HAB) program:

1- Support the goals of the Utah Lake Water Quality Study

- Understand the current water quality (nutrients, algae, and organic matter) in Utah Lake.

- Understand the nutrients loading to Utah Lake
- Support the development of a predictive water quality model
- Support the goals of the Utah Lake Science Panel

2- HAB Monitoring

- Phytoplankton and Cyanotoxin Testing for HABs
- Real time ambient Utah Lake water quality forecast for HABs (via Sonde deployments)

For more details about the field efforts the DWQ conducted in 2018, refer to the 2018 Utah Lake Sampling and Analysis Plan. This document detail all the field sampling efforts, lists the sites and parameters and explains the sampling approaches the DWQ undertakes to obtain a complete data set for the 2018 sampling season.

4.2.1 Open Water Monitoring

Every second Tuesday of each month during May- November, DWQ samples 13 lake sites which are also called open water sites (see Table 5 and Figure 2).

Table 5. Utah Lake Priority Open Water Sites.

MLID	Source	Site Name	Latitude	Longitude
4917600	OW	Utah Lake Goshen Bay Southwest End	40.060235	-111874384
4917500	OW	Utah Lake 3 Mile WNW of Lincoln Beach	40.169720	-111.870830
4917710	OW	Utah Lake 1 Mile NE of Lincoln Point#03	40.157728	-111.791325
4917715	EXO	Utah Lake 1 Mile East of Bird Island	40.168100	-111.776076
4917770	OW	Utah Lake Outside Entrance To Provo Bay	40.189450	-111.731390
4917450	OW	Utah Lake At Middle of Provo Bay	40.189170	-111.699170
4917388	EXO	Utah Lake 1 Mile West of Provo Bay	40.237877	-111.767671
4917390	OW	Utah Lake 1 Mile West of Provo Boat Harbor	40.237220	-111.763890
4917370	OW	Utah Lake 1 Mile East of Pelican Point	40.268283	-111.829930
4917520	OW	Utah Lake 2 Mile East of Saratoga Springs #12	40.342200	-111.870550
4917310	OW	Utah Lake 0.5 mi West of Geneva Discharge #15-A	40.320920	-111.776780
4917320	OW	Utah Lake 0.5 Mile West of Geneva Discharge #15-B (4917310 Duplicate)	40.320920	-111.776780
4917365	EXO	Utah Lake 2 Mile West of Vineyard, UT	40.299558	-111.801095

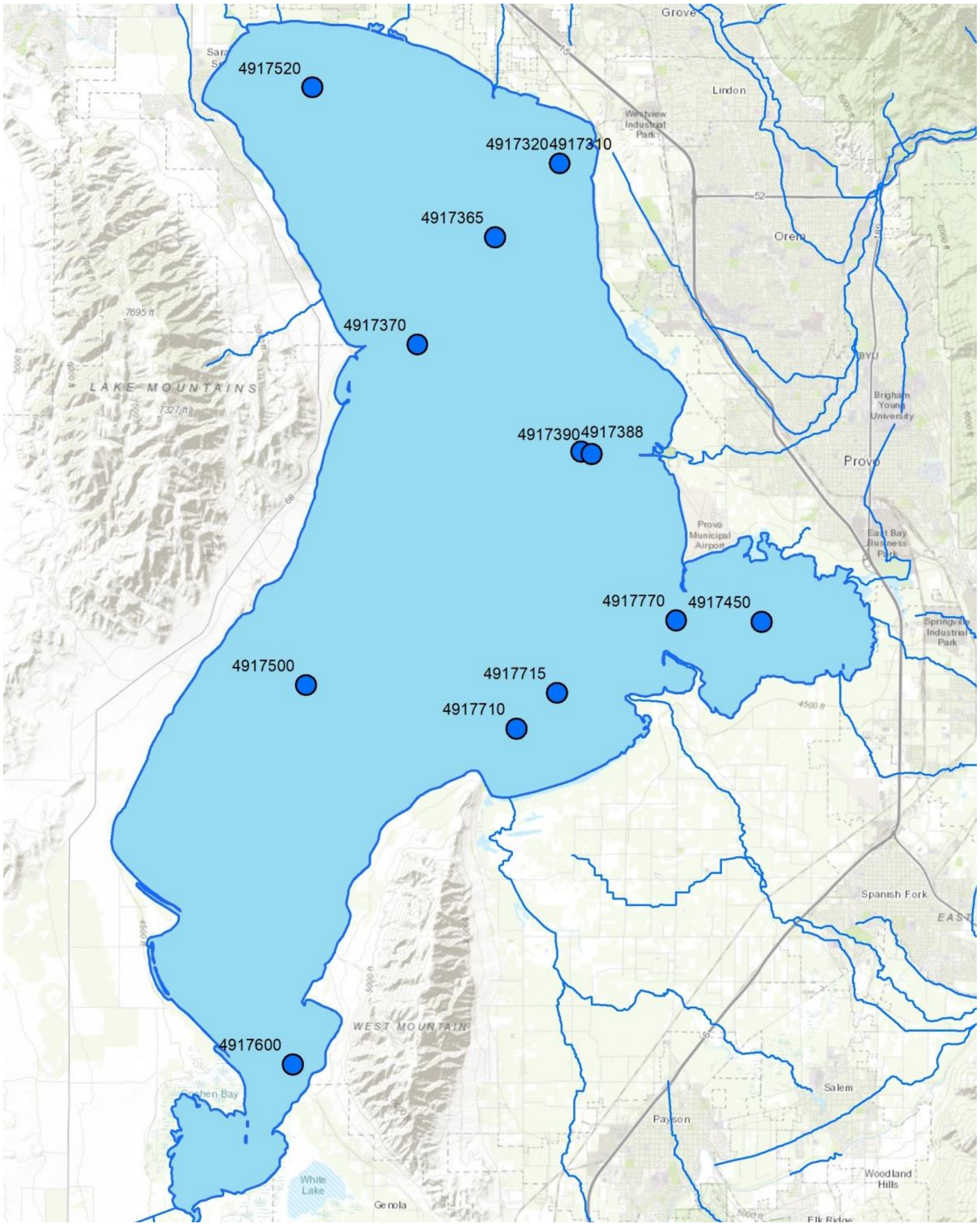


Figure 2. Utah Lake Open Water Monitoring Locations.

At each site, DWQ collects water chemistry samples to be able to understand the temporal and spatial condition of Utah Lake. Table 6 shows the chemical water quality parameters that are collected at each open water site. The DWQ field crew also documents observations of water depth, light penetration (secchi depth), color of the water column (for example gray, green, silty) and the presence of algal mats/scum whenever samples are collected.

Table 6. Water Quality Parameters collected at open water sites.

Water Chemistry Parameters to be Analyzed for Utah Lake Open Water Sites (Monthly Monitoring)	
Field Parameters	Temperature, Specific Conductance, pH, Dissolved Oxygen, and Secchi depth
Sonde Parameters	Temperature, Specific Conductance, pH, Dissolved Oxygen, Turbidity, Chlorophyll *a* and Phycocyanin
Non-filtered Nutrients	Ammonia, Nitrate/Nitrite, Total Phosphorus, Total Nitrogen, and Total Organic Carbon
Dissolved (Filtered) Nutrients	Ammonia, Nitrate/Nitrite, Total Dissolved Nitrogen, Dissolved Organic Carbon, Dissolved Phosphate
General Chemistry	Alkalinity, Chlorine, Specific Conductance, Sulfate, Total Dissolved Solids, Total Suspended Solids, Turbidity, and Total Volatile Suspended Solids
Filtered metals	Calcium, Magnesium, Potassium and Sodium
Others	Chlorophyll-a, *E*.coli , Cyanotoxins and Phytoplankton

4.2.2 High Frequency Monitoring

During the period 2016-2018, DWQ coordinated long-term (~seven months) buoy deployments at three representative locations to provide an early warning of harmful algal blooms. The buoys are equipped with multi-parameter data sondes and a telemetry system allowing real time collection and analysis of data which allowed DWQ to characterize diurnal variations in temperature, pH, specific conductance, and dissolved oxygen. In addition, these buoys served as an early warning system for identifying potential increases in cyanobacteria to guide algal and cyanotoxin sampling for public warnings and protection of human health. Table 7 shows detailed information about the location of each buoy. Every 15 minutes, these sondes record dissolved oxygen, pH, specific conductivity, water temperature, turbidity, chlorophyll *a*, and phycocyanin within the photic zone. Deployments capture the critical HAB season from July through September.

Table 7. Utah Lake Buoy Sites.

MLID	Site Name	Latitude	Longitude
4917715	Utah Lake 1 Mile East of Bird Island	40.1681	-111.776
4917388	Utah Lake 1 Mile West of Provo Bay	40.23788	-111.768
4917365	Utah Lake 2 Mile West of Vineyard, UT	40.29956	-111.801

4.2.3 Tributary Monitoring

4.2.3.1 Monthly Sampling

DWQ also collects environmental samples to characterize water quality conditions in the major tributary sites contributing inflows to Utah Lake. Every month DWQ samples 17 tributary sites (see Table 8 and Figure 3).

Table 8. Major Tributary Sites.

MLID	Site Name	Latitude	Longitude
4995465	BEER CREEK/BENJAMIN SLOUGH	40.13287	-111.791
5919910	DRAIN AT 4000 WEST 5000 SOUTH	40.14387	-111.749
4995578	SPANISH FORK RIVER AT UTAH LAKE INLET	40.15779	-111.731
4996100	HOBBLE CK AT I-15 BDG 3MI S OF PROVO	40.18401	-111.647
4996275	SPRING CK AT I-15 FRONTAGE ROAD	40.18956	-111.649
4996566	PROVO STATION 6-WLA	40.20191	-111.655
4996540	MILL RACE CREEK AT I-15 CROSSING (2 MI S PROVO COURTHOUSE)	40.20311	-111.656
4996677	PROVO RIVER	40.23694	-111.732
4995038	TIMPANOGOS Special service District	40.33713	-111.777
4995041	TIMPANOGOS TRIBUTARY	40.33663	-111.777
4994960	AMERICAN FK CK 2.5MI S OF AM FK CITY	40.3438	-111.802
4994950	SPRING CK BL LEHI MILL POND	40.36305	-111.835
4994804	DRY CREEK AT 145 N (SARATOGA SPRINGS)	40.36504	-111.884
4994792	SARATOGA SPRINGS AT CEDAR VALLEY	40.35242	-111.902
4995210	POWELL SLOUGH WMA NORTH OUTFALL TO UTAH LAKE	40.26524	-111.743
4995230	POWELL SLOUGH WMA SOUTH OUTFALL TO UTAH LAKE	40.26309	-111.741
4996040	DRY CK NEAR UTAH LAKE-WLA	40.18149	-111.672

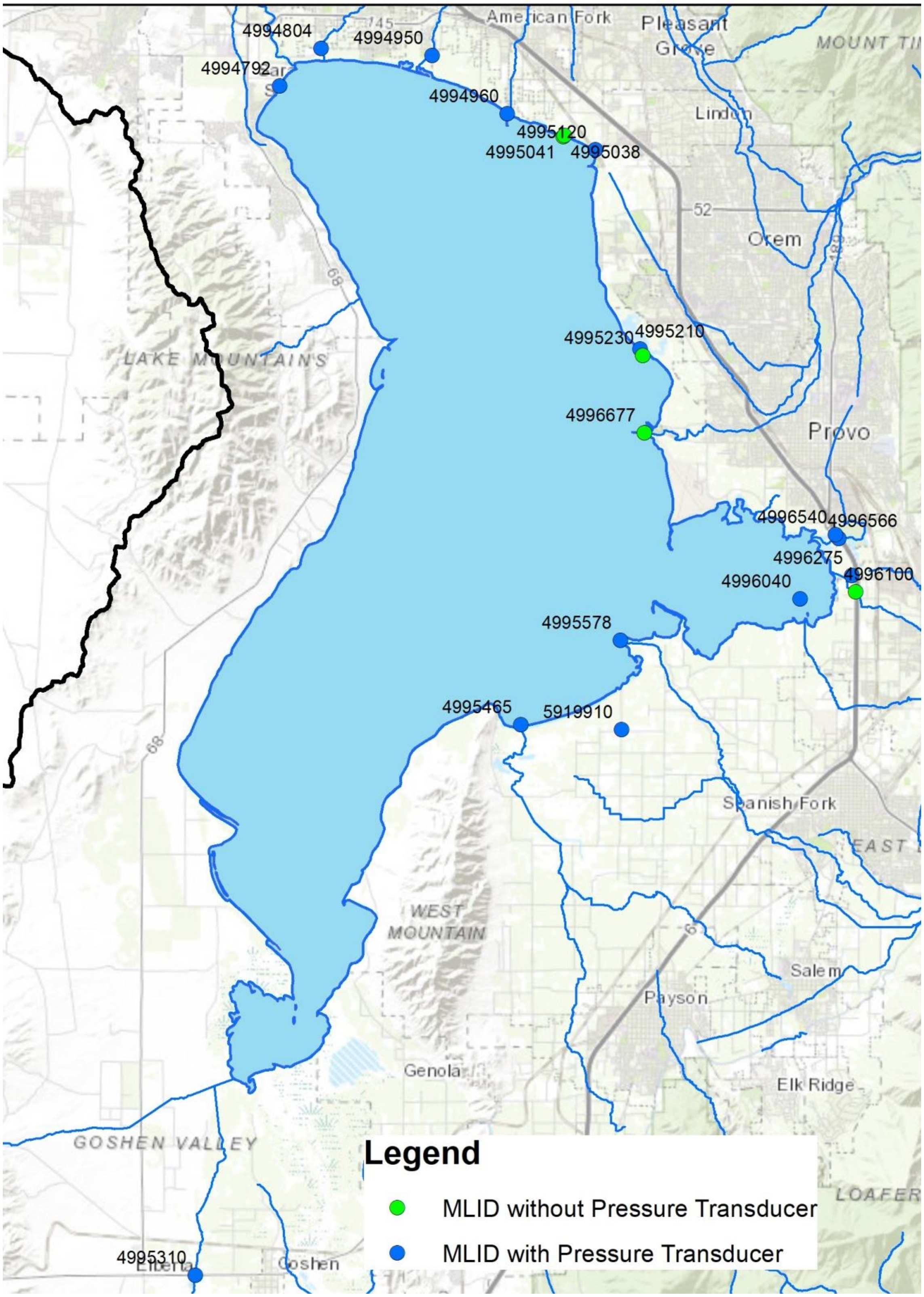


Figure 3. Tributary Monitoring Locations.

Water chemistry samples collected from these major tributaries help DWQ better understand the temporal and spatial variability of water quality conditions surrounding Utah Lake. Table 9 shows the chemical analytes (water quality parameters) that are collected at each site. The DWQ also documents the presence of algal mats and Phragmites whenever samples are collected.

Table 9. Water Quality Parameters for Tributary sites

Water Chemistry Parameters to be Analyzed for Utah Lake Tributary Sites (Monthly Monitoring)	
Field Parameters	Temperature, Specific Conductance, pH, Dissolved Oxygen, and Secchi depth
Biochemical Oxygen Demand (BOD)	Carbonaceous BOD5 (cBOD5) only at Wastewater Treatment Plants
Non-filtered Nutrients	Ammonia, Nitrate/Nitrite, Total Phosphorus, Total Nitrogen, and Total Organic Carbon
Dissolved (Filtered) Nutrients	Ammonia, Nitrate/Nitrite, Total Dissolved Nitrogen, Dissolved Organic Carbon, Dissolved Phosphate
General Chemistry	Alkalinity, Chlorine, Specific Conductance, Sulfate, Total Dissolved Solids, Total Suspended Solids, Turbidity, and Total Volatile Suspended Solids
Others	Chlorophyll-a and *E.*coli

4.2.3.2 Pressure Transducer Monitoring

In November 2017, DWQ deployed ten pressure transducers (PTs) in tributary streams. These PTs are a low-cost and robust method of determining near-continuous flow in streams that are not gaged by another agency such as the U.S. Geological Survey or a utility. The transducers are programmed to log depth of water every 15 minutes. Recorded values are stored in the sensor itself and are periodically retrieved by field personnel. By combining these logs of depths with a number of discharge measurements taken at the site, a rating curve can be developed, correlating the depth of water with the measured discharge. Once this correlation is established, discharge may be inferred from water depth alone.

4.3 Utah Lake Water Quality Database

In 2016, DWQ began requesting data from all the monitoring partner entities. DWQ used the meetings held in February 2016, October 2016 and May 2017 as a reminder to encourage each group to submit any Utah Lake related data that they might have. Unfortunately, some research groups were concerned about sharing the data before submitting manuscripts thus the agency did not receive all the requested data. DWQ was however able to compile the following historic data;

- Field data collected from sonde(s)
- Phytoplankton
- Water chemistry
- USGS data
- Zooplankton
- Utah Lake water elevation

The DWQ also compiled pressure transducer, flow and chlorophyll-a data. Table 10 shows in detail the data type, entity collecting the data type and the status of the data.

4.3.1 Data Matrix

Table 10. Data Matrix showing available data resources.

Data Type	DWQ	USGS	USU	BYU	UU	UVU	WFWQC	CUWCD	Larry Gray	Water Rights
Water Chemistry	Final			Final	RNR	RNR	IP	Final		
Flow-USGS		Final								
Flow	Final						IP			
Lake Elevation			Final							Final
Pressure Transducer	Final									
YSI Sondes or Aqua Troll 600	Final									
EXO Sondes	Final									
CHL-A	Final						IP			
Discharge Monitoring Report	Final									
Monthly Operating Report	IP									
Sediment					RNR		IP			
Macro-invertebrate							IP			
Phytoplankton	Final									
Zooplankton			Final						Final	
Vegetation Monitoring						RNR				
Macrophytes and Phragmites			RNR			RNR				
Fish Sampling						RNR				

Note: PR: Provisional PA: Partial F: Final RNR: Requested not received IP: In Progress

4.4 *Literature Synthesis*

A bibliography of Utah Lake literature, studies, and theses was assembled during the development of the *Utah Lake Pollutant Load Assessment Report* (DWQ, 2008). This bibliography was updated with studies available from local universities, researchers, and other readily available sources. A significant new source of publications is available from the Lake Ecology Laboratory, managed by Dr. Jereme Gaeta at Utah State University (Gaeta, 2018). These bibliographies were assembled into a single format and are available in Appendix A – Utah Lake Bibliography.

5 Utah Lake Data Explorer

5.1 Introduction

To facilitate rapid analysis of a wide range of water quality characteristics in Utah Lake, DWQ has developed an interactive data visualization tool called the Utah Lake Data Explorer (ULDE). The ULDE is built on the R statistical platform (r-project.org) using the R package, Shiny (shiny.rstudio.com). The ULDE product is an interactive web-app that allows users to generate a variety of Utah Lake specific data visualizations as real-time responses to date, parameter, and analysis type selections. More broadly, the ULDE could also serve as a platform for conducting future analyses as desired by the Utah Lake Steering Committee or Science Panel. The automated platform also streamlines the process of updating plots and analyses as additional data are generated.

5.2 Objectives

The objectives of the ULDE are to enable science panel members, steering committee members, and other stakeholders to:

1) Rapidly visualize and understand basic patterns in water quality conditions in Utah Lake,

2) Compare conditions in Utah Lake to those observed in other lakes throughout the nation, and

3) Generate and evaluate hypotheses about Utah Lake.

5.3 Usage

Application usage is relatively simple. For all modules of the ULDE, users select desired ranges of years and months, parameters, fractions, and sample depths, and select the desired analysis or plot type. Excepting the *'Water quality map'* tab, plots are reactively updated on user inputs. On the *'Water quality map'* tab, the map is only updated when the user clicks the 'Interpolate' button. This is to prevent app slow-downs due to the data intensive nature of the interpolation. Brief descriptions for each module of the ULDE are provided at the top of the input side-panel. Plots from the first three tabs of the ULDE can be generated with uniform x-axes for comparison by selecting identical year ranges.

5.4 Access and Availability

The ULDE application is accessed through a web browser. The application is available without the installation of R and dependent packages through this web link: https://udwq.shinyapps.io/UtahLakeDataExplorer/. Access through the web link requires internet access. For those who would like to be able to work offline or access source code, a zip package of the application is also available for download for local installation. Running the ULDE locally requires the installation the R statistical package and several R packages. A readme file outlining local installation and operation of the ULDE is provided in the zip file.

5.5 Data Pre-processing Assumptions

Harmonizing the dataset for use in the ULDE requires some data pre-processing and certain assumptions regarding parameter names, fractions, and sampling depths to translate all parameters to uniform terminology. The key steps are described here. A full parameter translation table is available in the ULDE zip package.

Only data with “Final” QA/QC status are included in the ULDE. Provisional data were rejected. Samples missing parameter names, fractions, or sample depths and those that could not be clearly interpreted and translated to a uniform terminology were also rejected. Additional data will be added to the ULDE as they are collected, reviewed, updated, and finalized.

Temperature, pH, and dissolved oxygen data from samples collected as water column profiles are not currently included in the ULDE. These data were reviewed by DWQ through another set of tools as described in the following “Water Quality Assessment and Analysis” section.

All non-detect values were set to ½ of the sample detection limit for plotting and analysis.

There are three chlorophyll *a* parameter names in the Utah Lake data set including those specifying whether chlorophyll *a* values were corrected for pheophytin. There were no significant differences between these three groups of chlorophyll *a* values, and they were lumped to a single chlorophyll *a* parameter for plotting and analysis.

For chlorophyll *a* and total phosphorus based trophic state analyses, only samples from total fractions and surface depths were included.

Fractions marked as “Acid Soluble” were translated to “Total”.

Sample depths or fractions for parameters where one or both of those fields are not applicable (e.g. Secchi disk depth, pH, turbidity, etc.) were all translated to” N/A”.

All sample fractions for the parameter “Total dissolved solids” were translated to “Dissolved”. All sample fractions for the parameters, “Total fixed solids”, “Total suspended solids”, and “Total volatile solids” were translated to “Total”. All sample fractions for the parameter “Settleable solids” were translated to “Total”.

6 Water Quality Assessment and Analysis

Lakes and streams in the state of Utah are assigned to beneficial use classes which identify protected uses for each waterbody. Use-specific water quality criteria are established in State Rule (UAC R317-2) to protect beneficial uses. By comparing observed water quality conditions to relevant criteria, DWQ assesses and reports on the attainment of beneficial uses for water bodies in the state of Utah. Waterbodies not supporting their beneficial uses are assigned to a list of impaired waters termed the 303(d) list after the relevant section in the Clean Water Act.

In addition to numeric water quality criteria, waterbodies in Utah are also protected by a narrative criterion which specifies that, "It shall be unlawful, and a violation of these rules, for any person to discharge or place any waste or other substance in such a way as will be or may become offensive such as unnatural deposits, floating debris, oil, scum or other nuisances such as color, odor or taste; or cause conditions which produce undesirable aquatic life or which produce objectionable tastes in edible aquatic organisms; or result in concentrations or combinations of substances which produce undesirable physiological responses in desirable resident fish, or other desirable aquatic life, or undesirable human health effects, as determined by bioassay or other tests performed in accordance with standard procedures; or determined by biological assessments in Subsection R317-2-7.3."

This discussion expands on DWQ's most recent 303(d) assessment methods to determine whether the previously identified impairments in Utah Lake still occur and to identify any other additional impairments. See http://www.deq.utah.gov/ProgramsServices/programs/water/wqmanagement/assessment/index.htm for additional information on assessment methods and previous reports.

For this report DWQ has also performed a baseline analysis of several relevant water quality parameters, trophic state indices (TSI), and lake elevation data. This process included analyses of spatial and temporal patterns in water quality, relationships among water quality parameters and TSIs, and relationships between water quality parameters and lake elevation. These analyses are intended to provide a baseline characterization of water quality trends and patterns that can be used to inform future decisions regarding scientific studies, hypotheses to be tested, and potential management strategies for Utah Lake.

6.1 Beneficial use descriptions

Utah Lake is currently assessed for the following beneficial uses:

2B Infrequent primary contact recreation and for secondary contact recreation where there is a low likelihood of ingestion of water or a low degree of bodily contact with the water. Examples include, but are not limited to, wading, hunting, and fishing.

3B Warm water species of game fish and other warm water aquatic life, including the necessary aquatic organisms in their food chain.

3D Waterfowl, shore birds and other water-oriented wildlife not included in Classes 3A, 3B, or 3C, including the necessary aquatic organisms in their food chain.

4 Agricultural uses including irrigation of crops and stock watering.

6.2 Existing uses

In addition to the use of Utah Lake water for irrigation of crops, pasture and stock watering, it is also utilized extensively for secondary irrigation, both from the lake directly as well as from its outflow into the Jordan River.

Although Utah Lake is currently designated for infrequent contact recreation such as wading, hunting, and fishing, several other recreational uses have existed since 1975. These uses include boating, swimming, and water skiing. Because these uses have existed since 1975, DWQ is obligated to assess and protect their attainment in addition to the uses specifically established in rule. A rule change is in process to update the protected recreational use for Utah Lake from 2B to 2A to more accurately reflect the existing recreational uses. Use changes are conducted through DWQ's Water Quality Standards Program (https://deq.utah.gov/ProgramsServices/programs/water/wqmanagement/standards/) and reviewed by the Water Quality Board (https://deq.utah.gov/boards/waterquality/).

6.3 Previously identified water quality impairments

Utah Lake's aquatic life and agricultural uses were listed as impaired in 2002 for exceedances of the state water quality pollution indicator threshold value for total phosphorus (TP) of 0.025 mg/L and the total dissolved solids (TDS) criteria for irrigation and stock watering of 1,200 mg/L, respectively (Utah Administrative Code R317-2-14). In 2010, an aquatic life use (ALU) impairment was added based on PCB levels in fish tissues. In 2016, Utah Lake's recreational uses were identified as impaired for harmful algal blooms that had occurred in 2014. In addition, the Provo Bay portion of Utah Lake was split from the main body of the lake for assessment purposes and listed for aquatic life impairments of pH and total ammonia. Listings for PCB in fish tissue and total phosphorus were carried over to Provo Bay, and Provo Bay was delisted for TDS. See chapters four and five of the 2016 IR for additional details regarding previously identified water quality impairments (DWQ, 2016).

6.4 Objectives

The Water Quality Assessment and Analysis section of this report has two objectives:(1) Re-evaluate, confirm, clarify, or expand on the beneficial use assessment for Utah Lake conducted under DWQ's 2016 Integrated Report
(https://deq.utah.gov/ProgramsServices/programs/water/wqmanagement/assessment

/currentIR2016.htm), and (2) Provide a baseline analysis of relevant water quality parameters including analyses of temporal and spatial trends and relationships among water quality parameters in support of the broader Utah Lake study process.

6.5 Scope

This report is limited in scope to analyses of in lake water quality parameters. It does not include analyses of tributary water quality, lake bed sediments, or identify pollution sources. These issues will be addressed in future studies as appropriate with input from the Utah Lake Project Steering Committee, Science Panel, and DWQ. This assessment is limited to parameters for which water quality standards or beneficial use assessment methods are currently available. However, temporal and spatial patterns in these and other parameters can be visualized through the ULDE.

6.6 Monitoring Methods and Available Data

6.6.1 DWQ routine monitoring

Since 1989, DWQ has regularly monitored Utah Lake at eight locations (Figure 4). Samples collected at these locations have included water column profiles, water chemistry, and algae samples. However, the location, frequency, and measured parameters of sampling have varied through time. Where data were available at other sites, they were also included in this report. A full characterization of these data is available as part of the Phase 1 data aggregation report including the raw data. Water column profile data for temperature, dissolved oxygen, and pH were typically collected at the surface and at every meter of the water column depth. As part of the profile collection, Secchi depth is also measured. Surface water chemistry samples are collected from a depth of 0.5 meter. All water chemistry samples, except dissolved metals and algae, are collected at the surface. Dissolved metals samples are collected one meter above the bottom. The algal sample, which is analyzed for taxonomic composition and primary production (chlorophyll *a*), is collected as a composite sample from two times the depth of the Secchi disc reading to the surface up to a maximum of two meters. This assessment is primarily focused on data available up to the year 2016. However, assessments will continue to be updated as additional data become available.

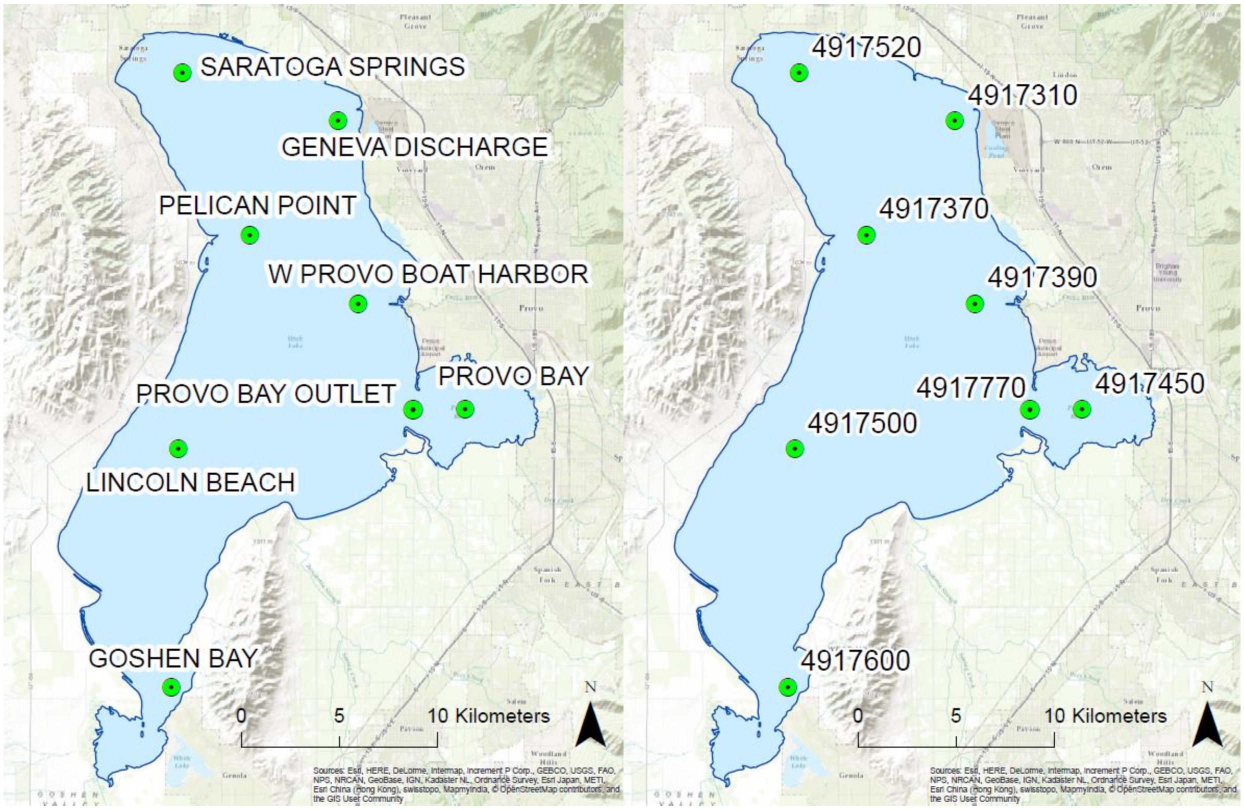


Figure 4. Map of UDWQ monitoring locations in Utah Lake labeled with location names (left) and identification numbers (right).

6.6.2 Harmful algal bloom monitoring

DWQ has actively monitored for harmful algal blooms (HABs) in Utah Lake since 2014. This monitoring is typically conducted in response to observed HAB occurrences and seeks to quantify potential exposure to cyanobacteria or cyanotoxins by targeting recreational access areas and observed algal scums for monitoring (https://deq.utah.gov/Divisions/dwq/health-advisory/harmful-algal-blooms/guidance.htm). HAB data were collected during the summers of 2014 and 2016 in response to observed blooms on Utah Lake. Results from the 2014 sampling are presented in chapter five of DWQ's 2016 Integrated Report (https://deq.utah.gov/ProgramsServices/programs/water/ wqmanagement/assessment/currentIR2016.htm#chapters). During the summer of 2016, DWQ and partner agencies collected 107 samples for cyanobacteria cell counts and 33 samples for cyanotoxin analyses from throughout the lake. Analyses of 2016 HAB data are described in this document.

6.6.3 High frequency data network

In the summer of 2016, DWQ installed a network of three monitoring buoys in Utah Lake. These monitoring buoys collect a variety of relevant parameters including pH, turbidity, chlorophyll *a*, dissolved oxygen, and phycocyanin at fifteen minute intervals. Although the buoys were operational for a relatively short time period in 2016 (August 26 – November 15, 2016), analyses of available data are not included in this report. DWQ anticipates continuing to deploy the buoy network approximately April through November in coming years. During 2016, these buoys were deployed at three sites: two miles west of

Vineyard (Vineyard), one mile west of Provo Marina (Provo Marina), and 1 mile west of Bird Island (Bird Island). Additional information and data from the buoy network are available through https://wqdatalive.com/public/669.

6.6.4 External data

External datasets are also often considered in DWQ's beneficial use assessments. As of this report, external datasets for Utah Lake are still undergoing review and considered provisional. Provisional data are not used in assessments, but may be used to update assessments as appropriate in the future.

6.7 Beneficial use assessment

6.7.1 Aquatic life use

6.7.1.1 Water column profiles

DWQ plotted water column profiles in Utah Lake to identify potential exceedances of 3B Aquatic Life Use standards for pH, DO, and water temperature (Table 11). Because Utah Lake is typically mixed and not stratified, pH, DO, or temperature exceedances in 10% of the water column including at least two points on the profile is considered impaired (2016 IR Assessment Methods).

Although temperature and pH occasionally exceeded the 3B Aquatic Life Use criteria within the water column, profiles did not identify temperature or pH impairments in portions of Utah Lake other than Provo Bay. At the Provo Bay monitoring location eight profiles identified pH impairments of the 23 collected.

DWQ examined DO profiles against both the 3B Aquatic Life Use early life stages (ELS) absent and ELS present minimum DO criteria (3 mg/L and 5 mg/L, respectively). Profiles did not identify impairments of the ELS absent DO criterion. Potential impairments of the ELS present criterion were occasionally observed throughout the lake. However, it is currently unclear where and when ELS are likely to be spatially and seasonally within the lake. In addition, it is important to note that DO assessments made from profiles collected under daytime conditions when algae are photosynthesizing and producing oxygen are likely to miss low DO values and may be insufficient for determining full beneficial use support. DWQ is currently working to enhance high frequency data collection in Utah Lake as well as throughout the state to help fill this data gap.

Table 11. 3B Warm water aquatic life use criteria for pH, temperature, minimum dissolved oxygen (DO), and 7 and 30 day average DO. ELS = early life stages present.

pH		Temp (°C)	DO (mg/L)				
Min	Max	Max	Min	ELS Min	30 d avg	7 d avg	7 d avg ELS
6.5	9	27	3	5	5.5	4	6

6.7.1.2 High frequency data

DWQ analyzed high frequency DO, temperature, and pH data collected from the Utah Lake buoy network from August 26 – November 15, 2016. It is important to note that although these parameters are collected at a high frequency, their use as an assessment tool may be limited by their fixed location and depth of collection as compared to the collection of water quality profiles. DWQ compared DO, pH, and water temperature data to applicable standards for Utah Lake (Table 11). In addition to comparing to the minimum DO values identified in Table 1, the collection of high frequency data allows comparisons to 7 day average standards for ELS present (6.0 mg/L) and ELS absent (4.0 mg/L) and to the 30 day average standard (5.5 mg/L).

The ELS present DO minimum standard was violated on two days at the Provo Marina site (Figure 5). No exceedances of the ELS absent DO minimum standard were identified. Similarly, no violations of the 7 or 30 day average standards were identified (Figure 5).

No exceedances of pH or water temperature standards were identified from these data (Figure 6).

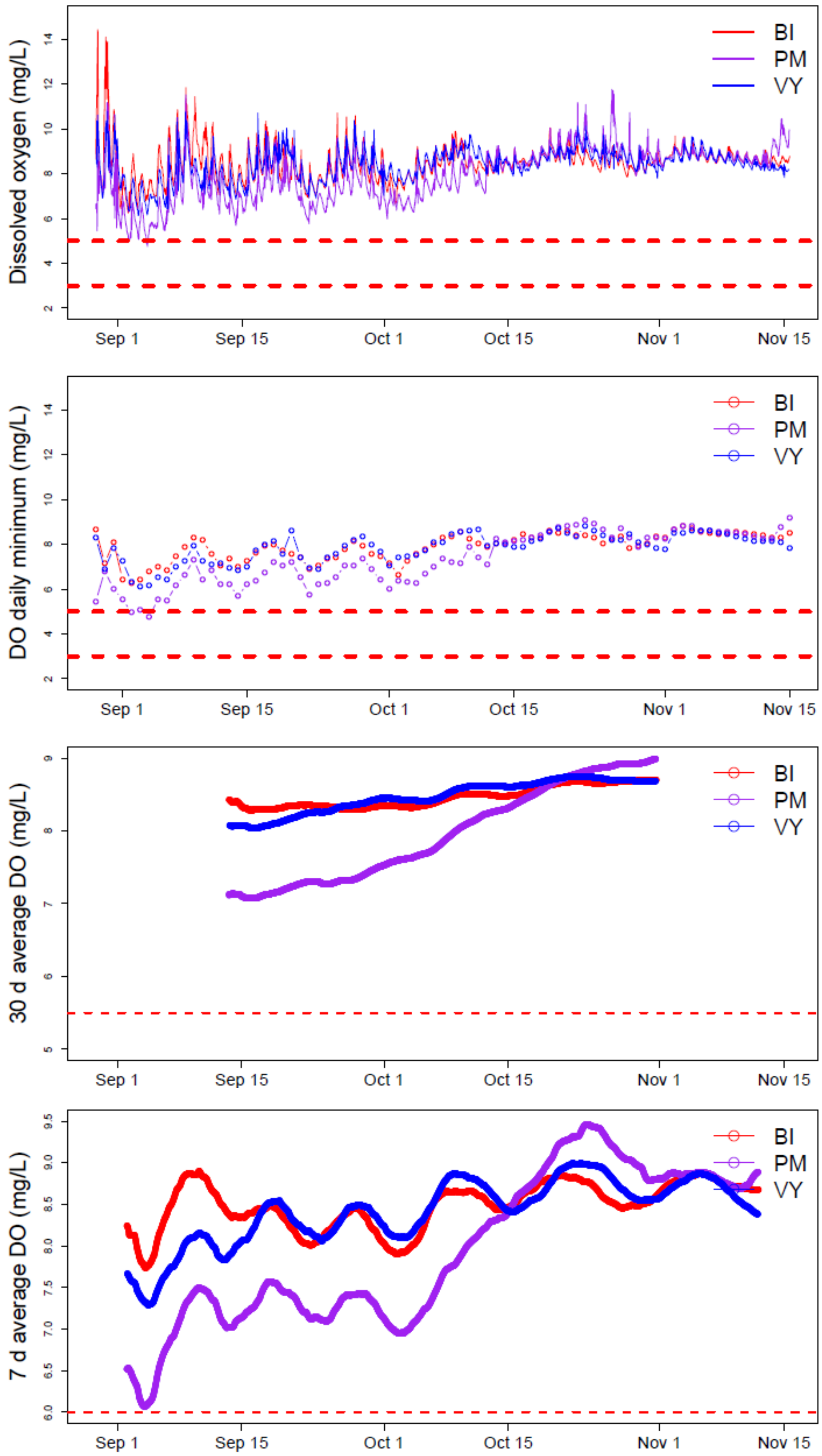


Figure 5. Dissolved oxygen data collected at three Utah Lake buoy sites in 2016. Plots show instantaneous values, daily minima, 30 day average, and 7 day average DO. Applicable standards are plotted as dashed red lines. BI = Bird Island, PM = Provo Marina, and VY = Vineyard site locations.

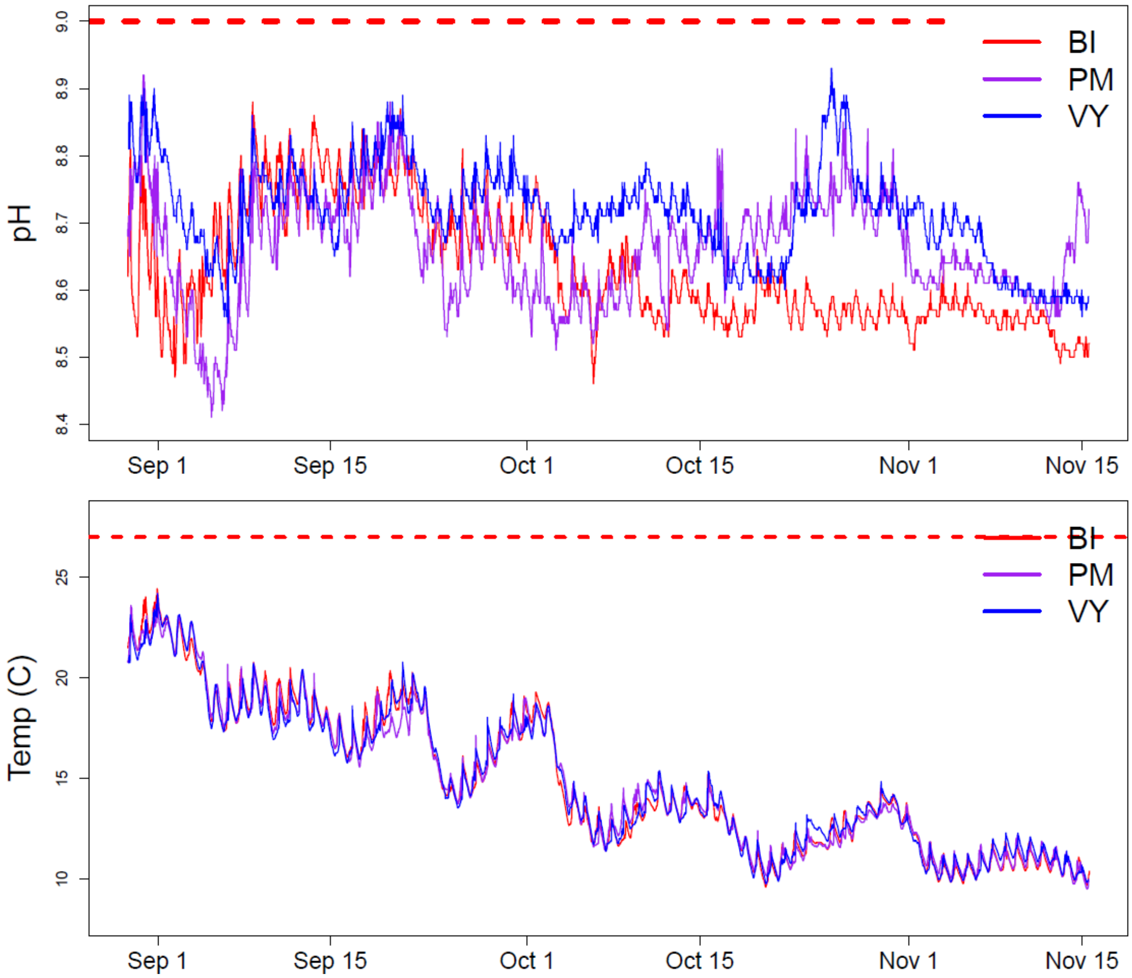


Figure 6. High frequency pH (top) and water temperature (bottom) data collected from the Utah Lake buoy network in 2016.Applicable standards are plotted as dashed red lines. BI = Bird Island, PM = Provo Marina, and VY = Vineyard site locations.

6.7.1.3 Ammonia

Total ammonia concentrations are generally low in the main body of Utah Lake. However, elevated concentrations occur in Provo Bay (MLID=4917450, Table 12 and Figure 7).Aquatic Life Use ammonia criteria are pH and temperature dependent. For all ammonia measurements with appropriately matching pH and temperature data, acute, chronic (30 day average) ELS absent, and chronic (30 day average) ELS present criteria were calculated and compared to observed ammonia concentrations. Acute ammonia exceedances were not observed in the main body of Utah Lake. Seven acute ammonia exceedances were identified in Provo Bay, all of which occurred under high pH conditions. Only one other site, Goshen Bay, experienced occasional exceedances of the chronic ELS present criteria.

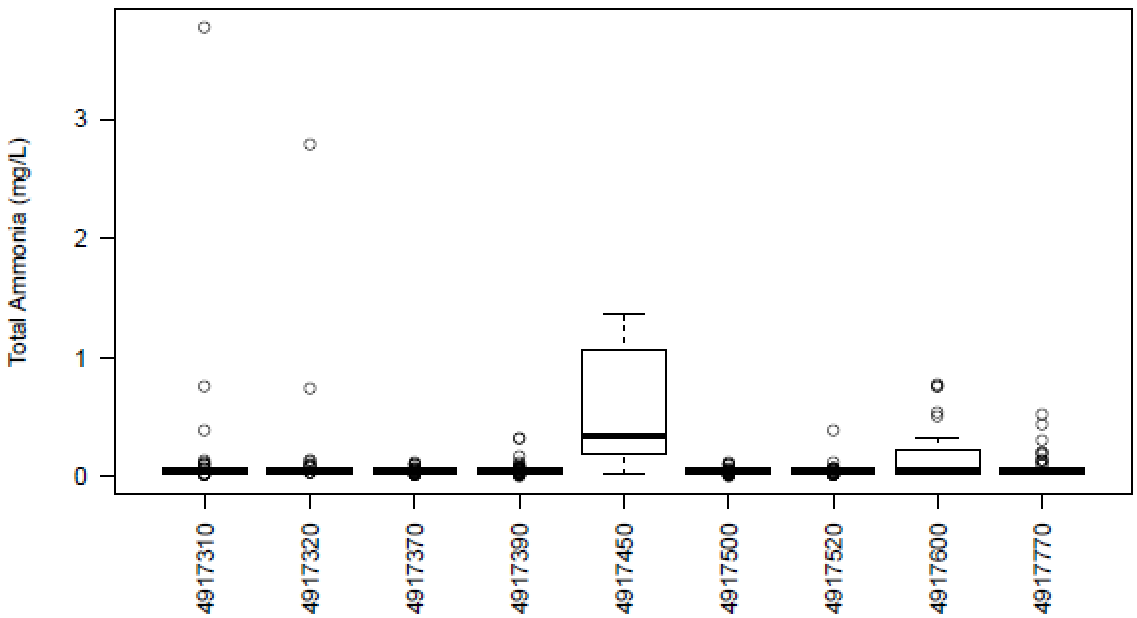


Figure 7. Total ammonia concentrations by site in Utah Lake.

Table 12. Ammonia criterion sample exceedance summary for Utah Lake.

	Sample Exceedance Count			Sample % Exceedance		
Site	**Acute**	**Chronic (30 d)**	**Chronic ELS (30 d)**	**Acute**	**Chronic (30 d)**	**Chronic ELS (30 d)**
4917310	0	2	2	0.0	4.2	4.2
4917320	0	0	0	0.0	0.0	0.0
4917450	7	10	11	29.2	41.7	45.8
4917600	0	4	4	0.0	16.7	16.7
4917770	0	0	0	0.0	0.0	0.0
4917520	0	1	1	0.0	1.8	1.8
4917390	0	2	2	0.0	3.8	3.8
4917500	0	0	0	0.0	0.0	0.0
4917370	0	0	0	0.0	0.0	0.0

6.7.1.4 Metals

Impairments for dissolved metal water quality standard exceedances have not been identified in Utah Lake. A total of 12 dissolved metal samples taken in Utah Lake were assessed for the 2016 IR against dissolved metal aquatic life use standards (pH and hardness corrected as appropriate). No exceedances of dissolved metal standards were identified. DWQ will continue to monitor and assess dissolved metal concentrations in Utah Lake in conjunction with the routine assessment process.

6.7.2 Agricultural use

6.7.2.1 Total dissolved solids

Total dissolved solids (TDS) concentrations varied significantly in time and space in Utah Lake. Exceedances of the 4A agricultural use criterion for TDS (1,200 mg/L) typically occur during low water years (e.g. 2002-2004, 2015-2016, Figure 8). Exceedances occurred at all sites except Provo Bay (Figure 8).

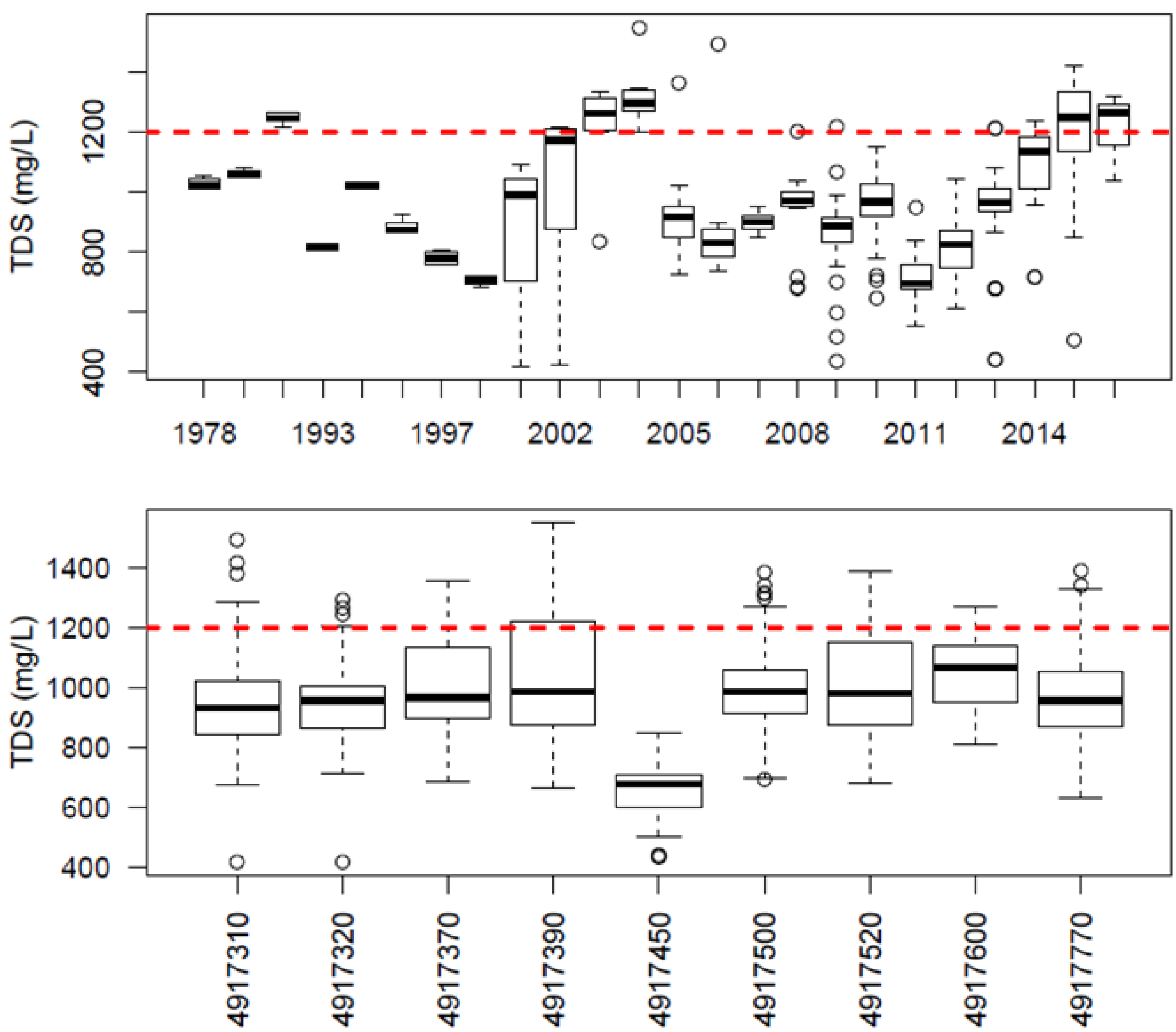


Figure 8. Total dissolved solids (TDS) concentrations by year (top) and site (bottom) in Utah Lake. The 4A agricultural use criterion for TDS (1,200 mg/L) is plotted as a dashed red line.

6.7.2.2 Harmful algal blooms

Harmful algal blooms (HABs) may negatively impact agricultural uses by exposing humans, crops, and livestock to cyanobacteria and cyanotoxins through the irrigation of crops and stock watering. DWQ is currently working with partner agencies and stakeholders to incorporate appropriate sampling procedures and methods for characterizing and assessing HAB impacts on agricultural uses. Therefore, a formal assessment of these impacts has not been fully conducted here. However, during the Utah Lake HAB events of 2016, irrigation water was shut off or closed to use to avoid potential contamination of crops or exposure of humans and livestock to cyanobacteria or cyanotoxins. This loss of use suggests HABs in Utah Lake may have negative impacts on agricultural uses downstream. See the recreational use assessment section below for additional information regarding observed HABs in Utah Lake.

6.7.2.3 Secondary water uses

Utah Lake is a major source of secondary irrigation water throughout the Jordan River valley (Figure 9).Similar to traditional agricultural uses, secondary water uses may be impacted by TDS and HABs. However, the uses of secondary waters may differ from traditional agricultural uses and therefore may be differentially impacted by water quality issues. In particular, secondary water usage can occur in more urban environments where human exposure may be greater. DWQ is currently working to quantify secondary water use from Utah Lake and determine whether general agricultural use protections are also protective of secondary uses.

Figure 9. Irrigation canals sourced from Utah Lake.

6.7.3 Recreational use

6.7.3.1 E. Coli

A total of 12 *E. coli* sampling events were conducted in Utah Lake during the 2016 IR cycle (2008-2014). These samples identified Utah Lake as fully supporting the 2B recreational use for *E. coli*. However since the 2016 IR assessment was completed, an *E. coli* advisory was issued at Lindon Marina and additional monitoring identified exceedances of *E. coli* standards in Lindon Marina and at Lindon Beach north of the marina. Samples collected at Lindon Beach identified *E. coli* impairments under both 2A and 2B criteria. Samples collected in Lindon Marina would result in impairments under 2A criteria, but not 2B criteria.

6.7.3.2 Harmful algal blooms

Harmful algal blooms (HABs) were sampled during the summers of 2014 and 2016. However, satellite imagery and observed high algal growth in Utah Lake suggest that similar occurrences have likely happened in other years as well. A synopsis of the 2014 HAB event is available in chapter five of DWQ's 2016 Integrated Report (https://deq.utah.gov/ProgramsServices/programs/water/wqmanagement/assessment/currentIR2016.htm#chapters) where results from the 2016 sampling are presented.

A potential HAB was first reported to DWQ on July 12, 2016, and the first HAB samples were collected on July 13. At all sites, initial samples identified very high cyanobacteria cell densities, including several samples exceeding 15 million cells/mL (Figure 10). Cell densities gradually decreased at all locations through the end of September. Samples collected early in the bloom were generally dominated by cyanobacteria of the genus Aphanizomenon. However, assemblage composition varied through time and was also site-dependent (Figure 11). Assemblages in the open waters of Utah Lake and in the Jordan River at the outlet of the lake progressed from Aphanizomenon dominance to a mixture of Microcystis, Dolichospermum, and Aphanizomenon. Samples collected at beaches and marinas throughout the lake showed much greater variability in composition with assemblages including mixtures of Aphanizomenon, Dolichospermum, Geitlerinema, Microcystis, Oscillatoria, Phormidium, and Pseudanabaena (Figure 11). Of 108 samples collected for cyanobacteria cell counts, a total of 34 exceeded DWQ's current recreational use impairment threshold for HABs. These exceedances were observed in 18 unique locations over the course of about six weeks (July 13 – Aug 31, Figure 12).

During the HAB events of 2016, DWQ and partners also collected 33 samples for cyanotoxin analysis by enzyme-linked immunosorbent assay (ELISA). Targeted cyanotoxins included β-Methylamino-L-alanine (BMAA), anatoxin-a, cylindrospermopsin, microcystin, and saxitoxin. Microcystins were detected in eight of 33 samples. The three highest samples identified concentrations of 3.6, 9.5, and 698 µg/L. All three of these samples were collected on July 15, 2016 at either Lincoln Beach or Lincoln Marina and were associated with cyanobacteria assemblages dominated by Aphanizomenon (cell counts of 2 M, 3.7 M, and 43 M cells/mL, respectively) but also exhibited elevated concentrations of Dolichospermum (2,200, 25,000, and 225,000 cells/mL, respectively). The other five detections were all less than 1 μg/L. BMAA, anatoxin-a, cylindrospermopsin, and saxitoxin concentrations were all less than detection limits.

Although measured toxin concentrations through the 2016 HAB events were generally low, over 150 recreationists exposed to the bloom reported adverse health effects consistent with cyanobacteria exposure including vomiting, diarrhea, nausea, headache, and skin and eye irritation to the Utah Poison Control Center (UPCC). It is unclear whether these health effects resulted from irritation caused by cyanobacterial cells, unknown cyanotoxins, known cyanotoxins that went undetected, or other causes. However, these effects are consistent with those documented in epidemiological literature (e.g. Pilotto et al. 1997, World Health Organization 2003, Stewart et al. 2006). DWQ is currently working with UPCC to better characterize these reports and examine their potential linkages to HAB exposure.

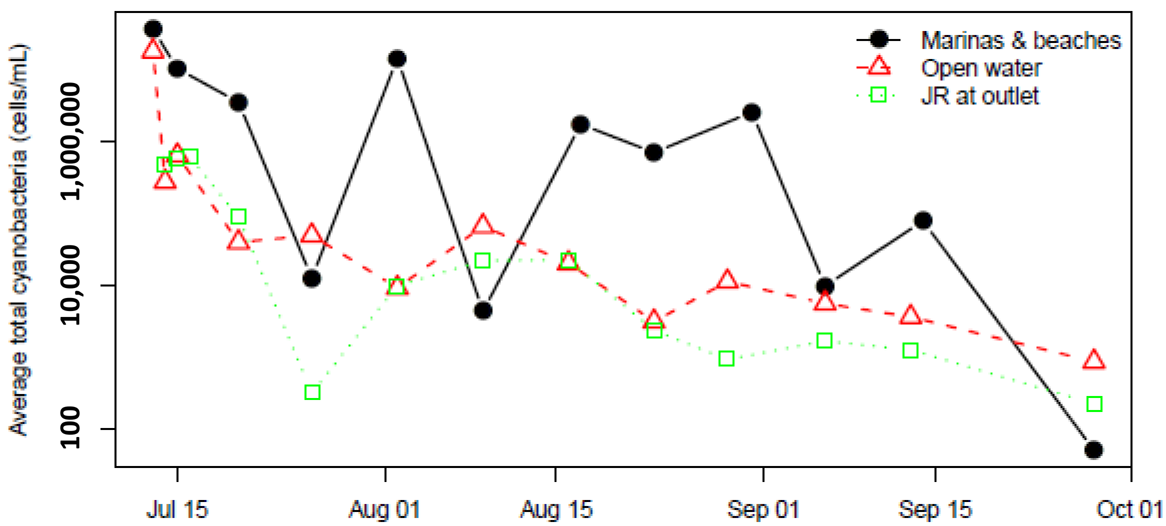


Figure 10. Cyanobacteria cell counts by location type during the 2016 HAB events on Utah Lake (July 13 – September 28). JR at outlet = Jordan River at the outlet of Utah Lake.

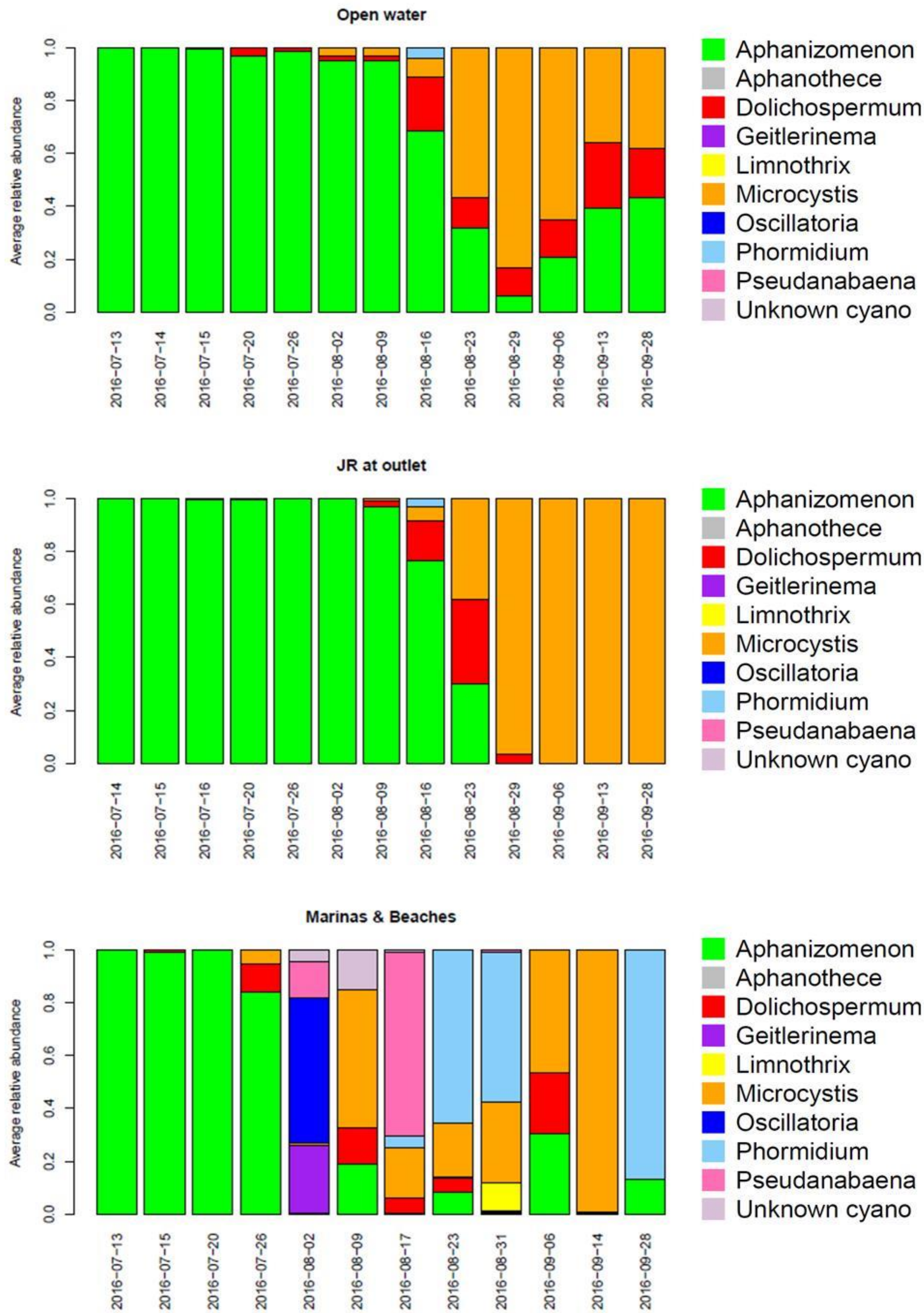


Figure 11. Average relative abundance of cyanobacteria genera by sample location type.

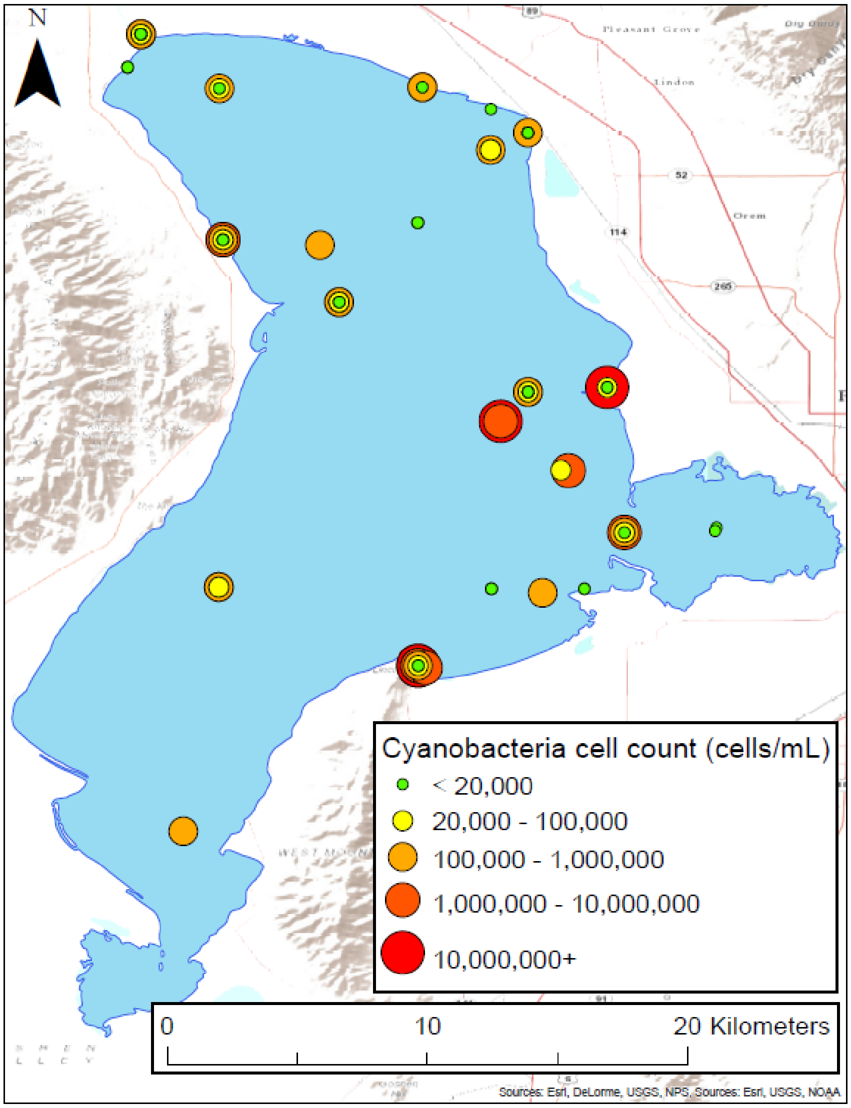


Figure 12. Cyanobacteria samples collected in Utah Lake during the 2016 HAB events (July 13 – September 28). Symbols are stacked by size to show multiple samples collected from the same location.

6.8 Trophic state analysis

6.8.1 Trophic state

The term, “trophic state,” is often used to describe the overall productivity of a lake. Ideally, this would be measured as the total biomass contained in a lake. However, given the impracticality of measuring total biomass, indicators such as chlorophyll *a* concentration, total phosphorus concentration, or water clarity as measured by Secchi disk depth are used to estimate trophic status. One method for estimating trophic state from these indicators is through the use of trophic state indices (TSI). A TSI is an estimate of total algal biomass based on one or more trophic indicators. Calculating TSI values effectively converts each of these measures with different units to comparable TSI units. Once calculated, these independent TSI indicators can be used to interpret how various factors interact to influence lake productivity (Carlson and

Havens 2005, Table 13). These differences can also be plotted and interpreted visually as in Figure 17 (Carlson and Havens 2005,).

DWQ calculated TSI values for surface samples of total phosphorus, chlorophyll *a*, and Secchi disk depth (Carlson and Simpson 1996). TSI values were then analyzed for spatial and temporal trends and compared between different TSI indicators. Additional plots and analyses beyond those presented in this report can be generated via the ULDE.

Table 13. Suggested interpretations of TSI relationships (adapted from Carlson and Havens 2005).

TSI Relationship	Suggested interpretation
TSI (Chl-a) = TSI (SD)	**Algae dominate light attenuation.**
TSI (SD) = TSI (Chl-a) ≥ TSI (TP)	Phosphorus limits algal biomass, and algae dominate light attenuation.
TSI (TP) > TSI (Chl-a) = TSI (SD)	Some factor other than phosphorus (zooplankton grazing, nitrogen, etc.) limits algal biomass.
TSI (Chl-a) < TSI (SD)	**Small particles, not necessarily related to algae, dominate light attenuation**
TSI (TP) = TSI (SD) > TSI (Chl-a)	Non algal particulate matter dominates light attenuation. Particles contain phosphorus, but do not contain chlorophyll.
TSI (SD) > TSI (Chl-a) = TSI (TP)	Dissolved color affects transparency but not chlorophyll or total phosphorus concentrations.
TSI (TP) > TSI (SD) > TSI (Chl-a)	Zooplankton grazing has reduced the number of smaller particles, leaving larger particles. Biomass has been reduced below levels predicted from total phosphorus.
TSI (Chl-a) > TSI (SD)	**Large phosphorus-containing particulates dominate.**
TSI (Chl-a) = TSI (TP) >> TSI (SD)	Large chlorophyll-containing particulates, such as Aphanizomenon flakes, dominate.

6.8.2 Spatial patterns

DWQ plotted TSI values by location to identify spatial patterns in trophic indicators (Figure 13). These patterns were also quantified statistically using analysis of variance (ANOVA) and Tukey's honest significant difference tests (Tukey's test) with 95% confidence. Secchi TSI did not vary significantly by site (ANOVA, Pr(>F)=0.16). Both chlorophyll *a* and TP TSIs varied significantly by site (both Pr(>F)<0.001).

Tukey's tests showed chlorophyll *a* TSI values were higher in Provo Bay than all other sites ($p \leq 0.001$ in all cases) except the Goshen Bay site (4917600). Similarly, TP TSIs were higher at the Provo Bay site (4917450) than the rest of the lake ($p < 0.001$ in all cases).In all sites other than Provo Bay, chlorophyll *a* and TP TSIs were statistically equivalent (Figure 13).

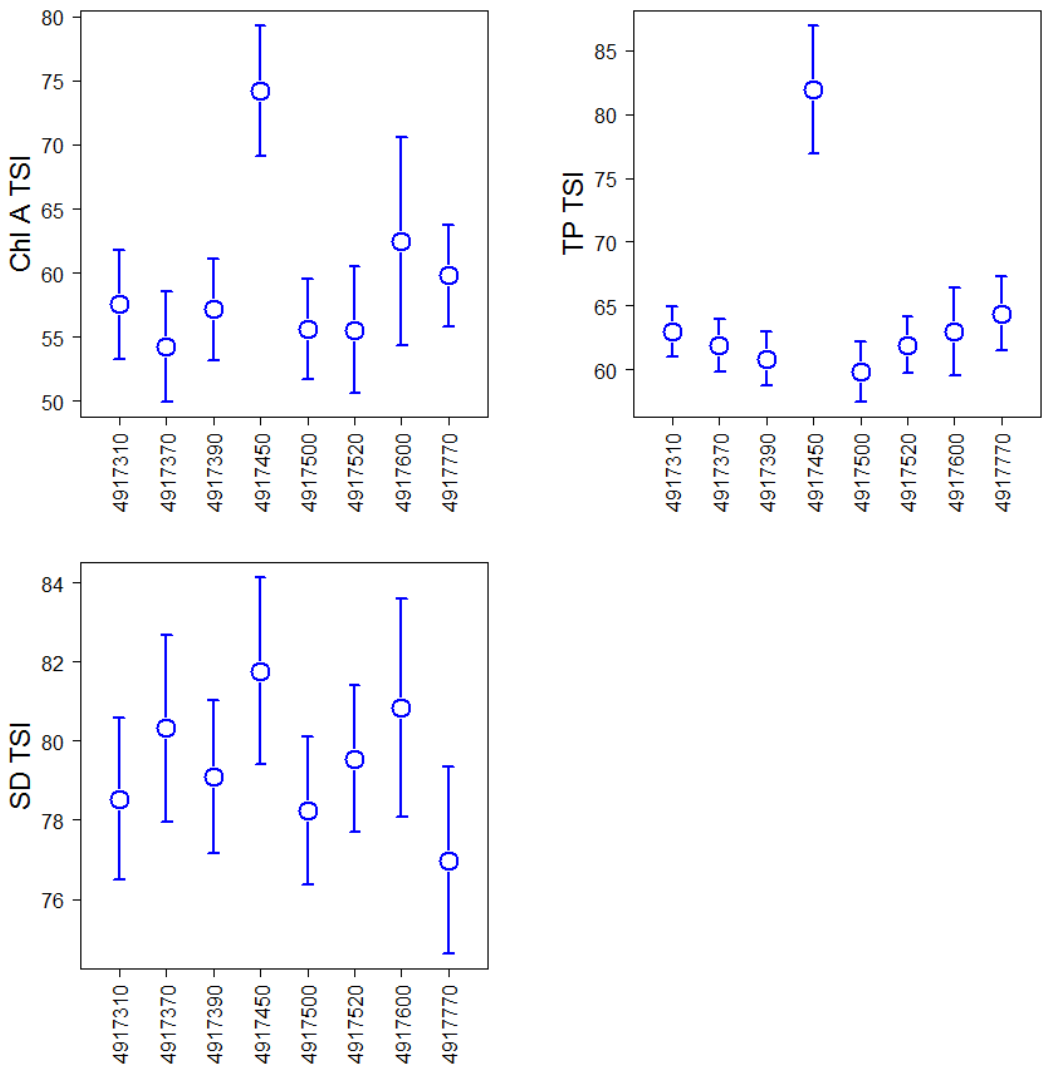


Figure 13. TSI values by site in Utah Lake. Plots show site means and 95% confidence intervals.

6.8.3 Temporal trends

DWQ plotted TSI values and observed lake elevations through time to help identify any temporal or seasonal patterns in water quality in Utah Lake and any significant changes that have occurred over the period of record.

Trends in TSI values over time were subtle (Figure 14). Chlorophyll *a* and TP TSI values decreased slightly ($p=0.01$, $p<0.05$), but the magnitude of change was small (≤ 5). Secchi disk TSI did not change significantly. Secchi TSI was consistently higher than either TP or chlorophyll *a* TSI values. With the exception of a few years in the early 2000s, TP and chlorophyll *a* TSIs were relatively equal, particularly from 2006 onward.

A slight seasonal pattern was evident in chlorophyll *a* TSI values demonstrating lower algal growth in May and June then increasing growth through the summer. Peak algal growth primarily occurred from August through October (Figure 15). Samples were only available for one or two unique dates in January, April, and November, limiting the interpretation of TSI values in those months. Clear seasonal patterns were not evident in TP or Secchi TSI values. As with the full time series, Secchi TSI was consistently higher than chlorophyll *a* or TP TSIs regardless of season. In May, June, and somewhat in July, chlorophyll *a* TSI was generally lower than TP TSI. However, during peak algal growth (August-October), chlorophyll *a* and TP TSIs were generally equivalent.

Annual average lake level fluctuated between 4479 and 4492 feet and averaged 4486 feet (Figure 14). Annual lake elevations and TSI values were not clearly related. Seasonal variations in lake elevation are also apparent with the lake rising October-April and falling May-September (Figure 15).

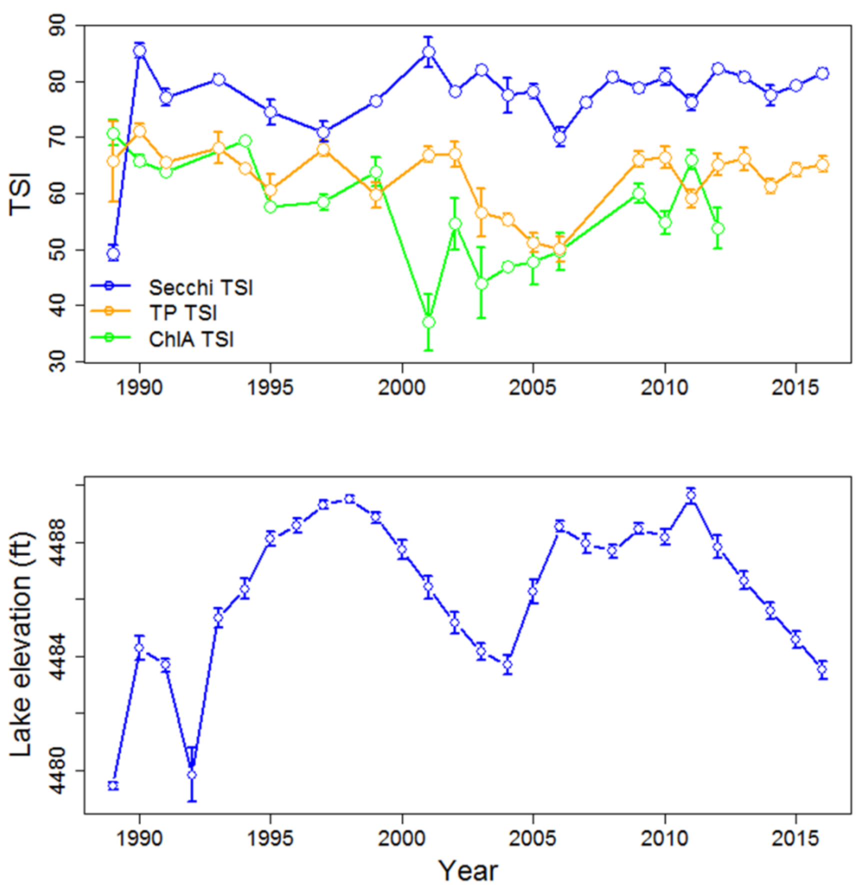


Figure 14. TSI values and lake levels through time in Utah Lake. Plots show annual means with 95% confidence intervals.

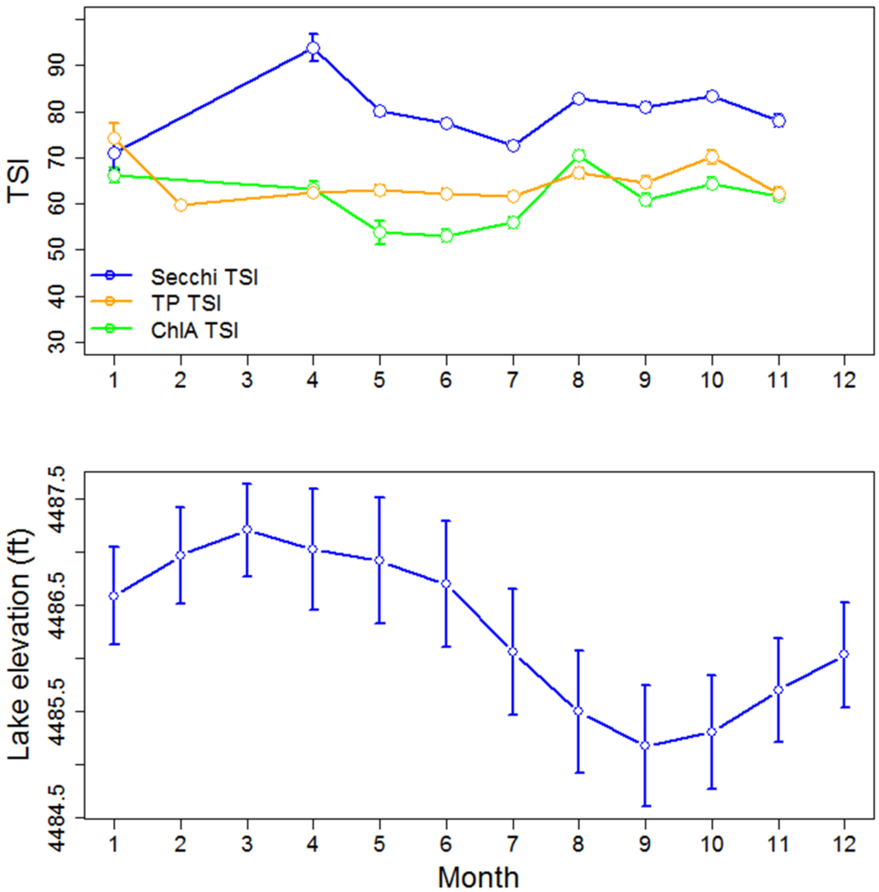


Figure 15. Seasonal trends in TSI values and lake elevation in Utah Lake. Plots show monthly means and 95% confidence intervals. Chlorophyll *a* samples were only available for one or two unique dates in January, April, and November, limiting the interpretation of TSI values in those months.

6.8.4 TSI difference analyses

DWQ examined relationships among and differences between the three TSI values graphically and statistically using ANOVA and Tukey's test. Observed differences were interpreted considering the suggested interpretations from Carlson and Havens (2005) outlined in Table 13. DWQ examined these relationships based on both the entire dataset and a subset of the data limited to the peak growing season identified above (August-October).

As identified by the temporal trend analyses, Secchi TSI is consistently higher than both chlorophyll *a* and TP TSIs regardless of season (Figure 16). Applying Tukey's test to data collected in all months, shows the TP TSI to be statistically higher than chlorophyll *a* TSI ($p<0.001$, Figure 16, bottom left); however, the difference is relatively small (<5 TSI units), and there is substantial overlap among the values (Figure 16, left). When the data are subset to the peak growth season (August-October), the chlorophyll *a* and TP TSI values are statistically equivalent (Figure 16, right). The same pattern (TSI SD > TSI TP ~= TSI ChlA) is apparent in the TSI difference scatterplot (Figure 17).

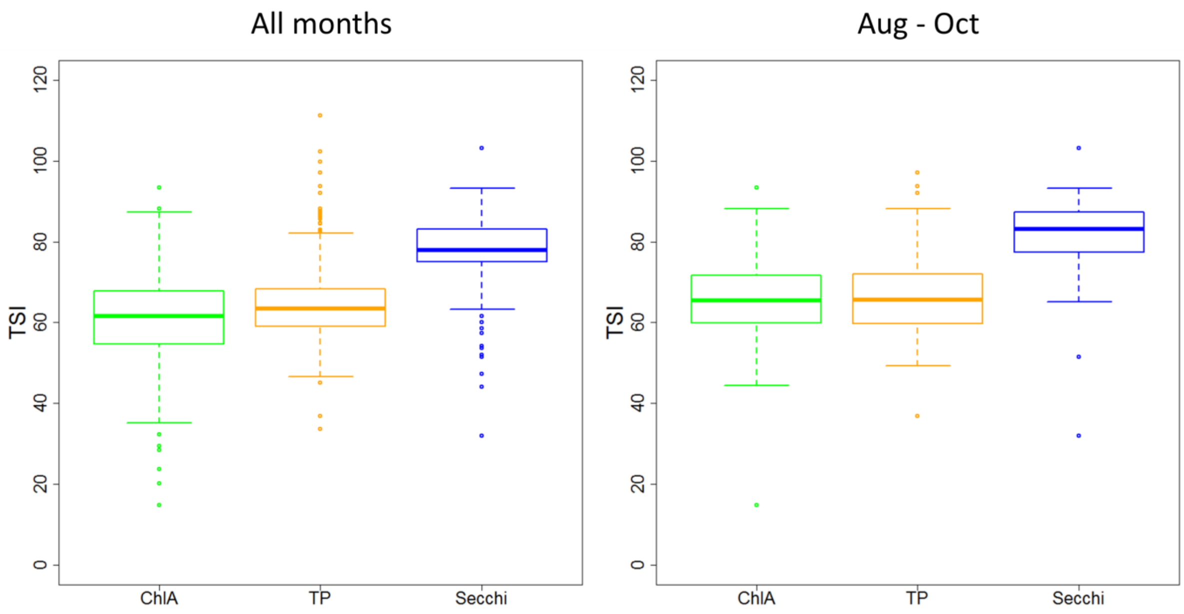


Figure 16. Boxplots of TSI values by indicator type in Utah Lake for all months (left) and the peak growing season (Aug – Oct, right).

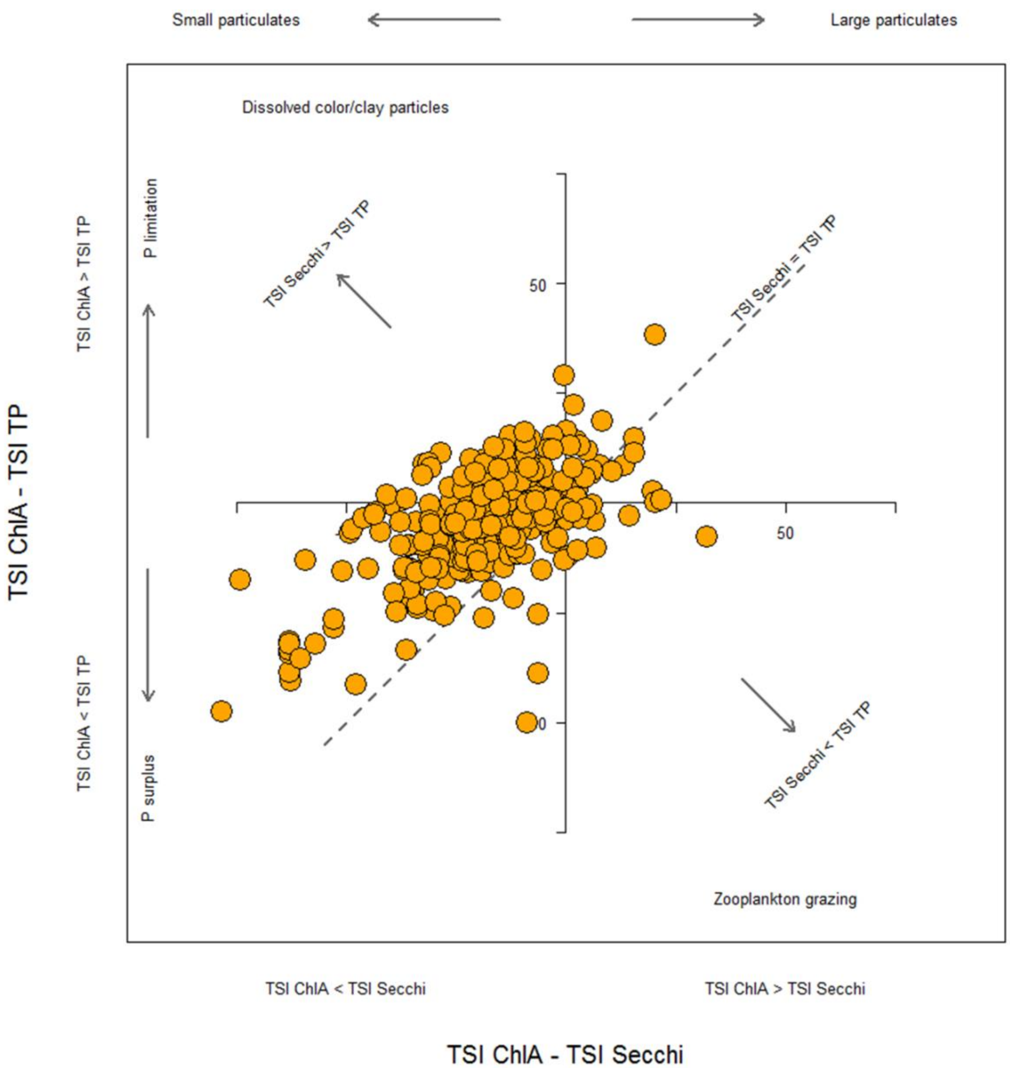


Figure 17. TSI difference scatter plot for Utah Lake. Crosses identify data centroids.

6.8.5 National context for Utah Lake's trophic status

To provide additional context for the relationships among trophic indicators in Utah Lake, DWQ compared the patterns identified above to those present in the National Lakes Assessment (NLA) dataset. The NLA uses a probabilistic sampling design resulting in a statistically representative sampling of the Nation's lakes. This dataset provides an excellent comparison point for relationships among trophic indicators in Utah Lake and for identifying any potential deviations from expected relationships based on a wide range of lake conditions.

Chlorophyll *a* and total phosphorus based TSI values in the main body of Utah Lake are typically within the 50^{th} to 75^{th} percentile of observed values nationally (Figure 18, left). Secchi disk TSI values in the main body of Utah Lake are consistently above the 75^{th} percentile of national lakes. TSI values from the Provo

Bay portion of Utah Lake are consistently above the 75th percentile of national lakes for all three TSI types (Figure 18, right).

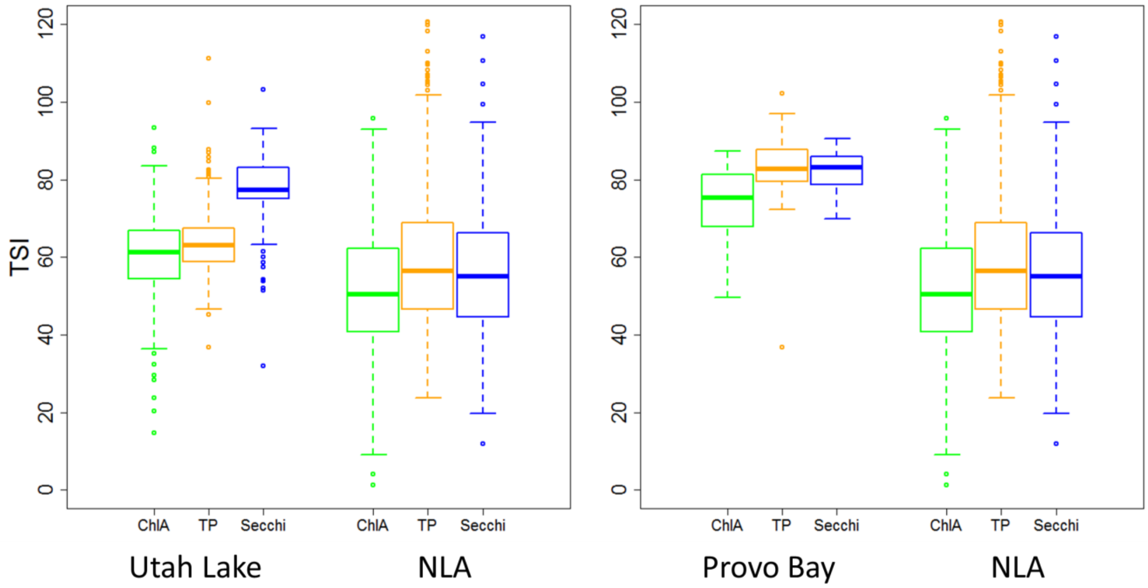


Figure 18. Chlorophyll *a* (ChlA), total phosphorus (TP), and Secchi disk depth based TSI values for sites in the main body of Utah Lake (left) and the Provo Bay portion of Utah Lake (right) compared to TSI values from the EPA National Lakes Assessment (NLA) dataset. Edges of boxes are 25th and 75th percentiles. Bands in the boxes are 50th percentiles.

The relationship between chlorophyll *a* and TP in Utah Lake is generally consistent with the relationship present in the NLA dataset, and chlorophyll *a* concentrations in Utah Lake are within the range expected based on TP concentrations (Figure 19, top left). Algal growth in Utah Lake is not suppressed relative to TP concentrations as would be expected if algal growth is limited by light, implying that algal growth in Utah Lake is either phosphorus limited or co-limited by phosphorus and nitrogen. In the NLA dataset, total nitrogen (TN), and chlorophyll *a* concentrations are also positively related (Figure 19, top right). However, TN data in Utah Lake is sparse, limiting the ability to quantify the relationship between chlorophyll *a* and nitrogen or compare this relationship to the NLA data. Recent collections of TN concentrations in Utah Lake should increase the ability to characterize this relationship in the future.

Secchi disk depth in Utah Lake is lower compared to the average of other lakes in the NLA dataset with similar ranges of chlorophyll *a* and TP concentrations (Figure 19, bottom left and right). This implies that a greater proportion of turbidity in Utah Lake is comprised of non-algal particulates than commonly observed in other lakes. However, the prevalence of non-algal particulates does not seem to have overwhelmed the relationship between chlorophyll *a* and TP or caused lower than expected algal growth relative to other lakes within a similar range of TP concentrations (Figure 19, top left).

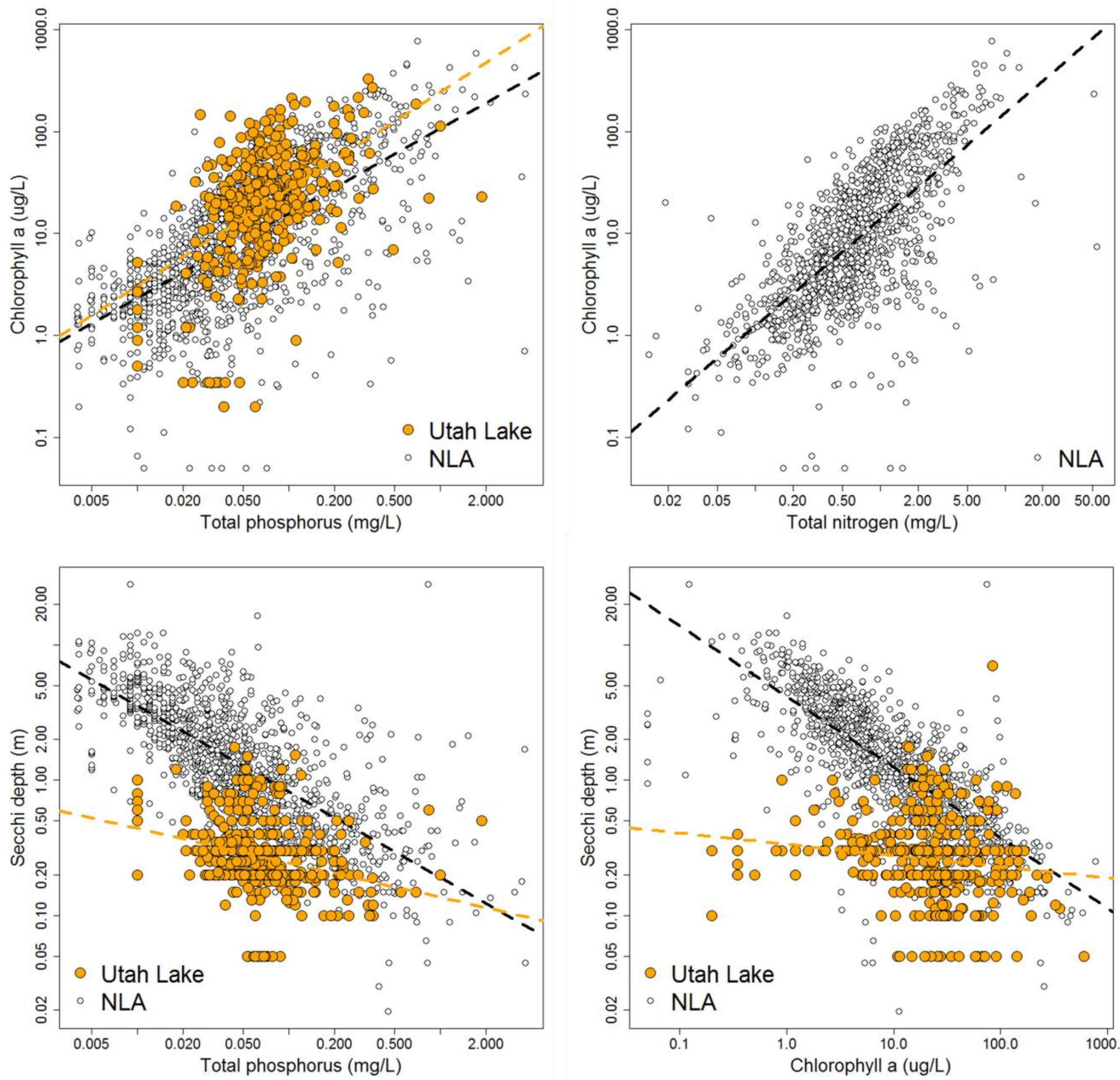


Figure 19. Relationships among trophic indicators in Utah Lake (filled orange) and in lakes nationally (hollow black). National regression lines are shown as black dashed lines. Utah Lake specific regressions are shown as orange dashed lines. NLA = EPA National Lakes Assessment.

7 Water Quality Model Selection and Development

The selection and development of a water quality model of Utah Lake was initiated as part of the Utah Lake Water Quality Study. The primary objective of the model is to function as a decision support and water quality management tool to address eutrophication in Utah Lake.

Following were the key objectives identified for the Utah Lake nutrient model:

1. Decision support tool for Utah Lake, including the relationship of phosphorus and nitrogen to water quality endpoints such as DO, pH, and nuisance and harmful algal blooms, as well as export of TP, TN and organic matter to the Jordan River.

2. Improve understanding of the nutrient dynamics in Utah Lake and the formation of nuisance and harmful algal blooms (cyanobacteria).

3. Predict effects of various nutrient loading scenarios on formation of nuisance and harmful algal blooms.

4. Predict transition of Utah Lake from turbid state to clear state, and vice versa.

A secondary objective of the nutrient model is to identify input and calibration data gaps and support planning of data collection efforts.

7.1 Model Selection

A model selection process was undertaken with a select committee of stakeholders referred to as the Utah Lake Modeling Group Members. The results of the model selection process are documented in the *Utah Lake Nutrient Model Selection Report* (UDWQ, 2016). The following selection criteria were considered in ranking each of the modeling platforms considered: complexity, capabilities, data requirements, transparency, flexibility, and compatibility.

The recommended modeling platform was a three-dimensional hydrodynamic model coupled with a water quality model. The selected hydrodynamic model was the Environmental Fluid Dynamics Code (EFDC) and the selected water quality model was Water Quality Simulation Program (WASP). Both models are supported by the EPA and have been widely applied for numeric nutrient criteria development and TMDLs.

7.2 Model Development

The EFDC-WASP Utah Lake model is being built and calibrated by a research team from the University of Utah under the direction of Dr. Michael Barber in the Civil and Environmental Engineering Department. The model development is occurring under a research grant from the EPA Office of Research and

Development (Barber et al. 2015). A Memorandum of Understanding was signed in September 2016 between the University of Utah, EPA Region 8 and UDWQ that stipulates substantial interaction and coordination between agencies on model development. Once the Utah Lake model has been calibrated by the University of Utah team, it will be made available to UDWQ for use in the water quality study.

7.3 Model Application

The calibrated Utah Lake model is anticipated to support the development of site specific criteria for nitrogen and phosphorus for Provo Bay and the open waters of Utah Lake. Depending on direction from the Science Panel, additional data collection and model calibration may be necessary prior to application of the model.

8 Utah Lake Loading Analysis

Watershed delivery of flow and nutrient loading to Utah Lake are important factors to understanding how nutrients are processed in the lake and the resulting quality of lake water. As prescribed by the model selection exercise discussed in section 7, simulation of in-lake water quality conditions will be accomplished by using a series of in-lake water quality and hydrodynamic models (EFDC and WASP). Since these models do not explicitly simulate delivery of flow and loading from the watershed to the lake, these parameters must be set as a boundary condition, meaning that inputs to the lake will be characterized outside of the in-lake model framework.

A number of techniques can be employed to estimate load and flow delivery to the lake including the characterization of monitoring data, simulation of watershed conditions with watershed-scale models, paired watershed statistical analyses, or some combination of these techniques. The Utah Lake Pollutant Load Assessment Report (DWQ, 2008) presented a reasonable analysis of flow and total phosphorus (TP) load entering the lake through tributaries, precipitation, canals, springs, and other significant sources.

This report characterizes current flow and loading conditions to Utah Lake and highlights a number of data gaps and assumptions to be addressed with future monitoring and evaluation. These limitations will be discussed in the following sections and include a discussion of information available to revising the lake water budget, load inputs to the lake, the role of the Utah Lake modeling effort, and recommendations for monitoring to fill data gaps.

For the purpose of this discussion flow and nutrient loading will be considered separately as: 1) water and loading delivered directly to the lake (Bulk Loading); and 2) nutrient loading from significant sources throughout the watershed (Source Allocation). Section 8 discusses bulk loading to the lake while section 9 evaluates watershed sources of nutrients.

8.1 Water Budget

A water budget, the accounting of all inflows and outflows for a hydrologic system, is a foundational product for estimating nutrient loading to Utah Lake. Existing water budgets were evaluated in the Utah Lake Pollutant Load Assessment Report (DWQ, 2008) and are summarized below. The Water Budget Data Characterization and sections below discuss ongoing efforts to improve the characterization of the Utah Lake water budget, which will lead to an improved understanding of nutrient loads delivered to the lake.

8.2 Direct Drainage and Ungaged Tributaries

The first step in this analysis was to differentiate watershed areas that flow into major tributaries from those areas that flow directly to Utah Lake. Figure 20 shows the results of a watershed flow routing analysis and differentiates the two watershed areas. Although direct drainage areas comprise only 8% of the total watershed area it makes up the majority of the lake shoreline and is an important component to the total nutrient loading to the lake with respect to irrigation return flows, stormwater discharges, groundwater drainage, and nutrients deposited below the lake's high water line. However, most monitoring locations are representative of tributary watershed areas with few monitoring locations within direct drainage and no monitoring locations along the base of Lake Mountain, Goshen Bay and West Mountain due to difficult access and lack of perennial flows. DWQ and the Utah Lake Watershed Coordinator are currently taking inventory of canals, drains, streams, and other channel types to guide future monitoring and characterize direct drainage nutrient contributions.

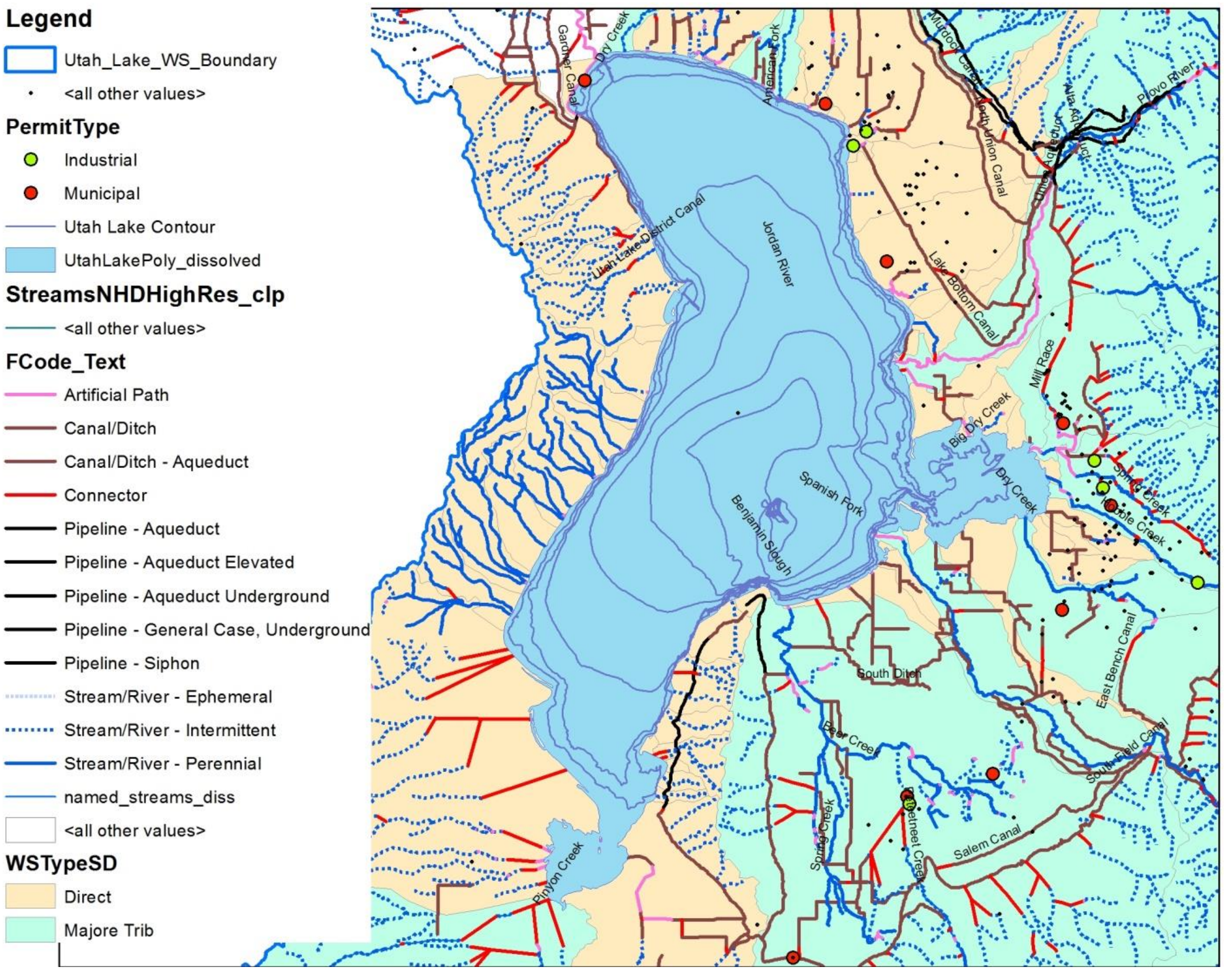


Figure 20. Utah Lake Direct Drainage and Tributary Watersheds.

8.2.1 Utah Lake Inflows

In order to characterize Utah Lake inputs, permitted, verified, and potential sources need to be identified and linked to a visual map and high quality data. Some of the inputs and outfalls are documented and mapped by local cities, municipalities and service districts. However, many natural and man-made perennial inputs are not monitored for flow. This section aims to identify sources not currently being accounted for in Utah Lake's water budget.

8.2.1.1 Identification of Direct Drainages

To help identify potential inputs not currently sampled by the UDWQ, local resource managers were contacted for information including city water managers, canal and irrigation companies, and individual land owners (Table 14 and Table 15).

Table 14. Cities and Water Service Districts within Utah Lake Watershed.

Saratoga Springs	Orem	Payson
Eagle Mountain	Provo	Salem
Lehi	Springville	Elk Ridge
American Fork	Spanish Fork	Woodland Hills
Alpine	Mapleton	Spring Lake
Pleasant Grove	Palmyra	Santaquin
Lindon	Lake Shore	Genoa
Vineyard	Benjamin	Genola
Cedar Hills	Elberta	Goshen
Cedar Valley	Orem Metro	Mosida
Timpanogos SSD	Santaquin	Fairfield

Table 15. Irrigation, Canal and Drain Companies Within Utah Lake Watershed.

Company Name	Community
Alpine Irrigation Co.	Alpine
Big Hollow Irrigation Co.	Springville
Bradford Acres Water Association	Spanish Fork
Cedar Valley Water Co.	Eagle Mountain
Currant Creek Irrigation Co.	Elberta
D & K Fowler Enterprises LLC	Lehi
East Bench Canal Co.	Spanish Fork
East River Bottom Water Co.	Provo
East Santaquin Irrigation Co.	Santaquin

East Warm Creek Irrigation and Canal Co.	Genola
Elberta Water Co.	Elberta
Fairfield Irrigation Co.	Fairfield
Goshen Irrigation and Canal Co.	Goshen
Harvest Irrigation Co.	Lehi
Lake Shore Irrigation Co.	Spanish Fork
Lakeside Irrigation Co.	Spanish Fork
Lehi Irrigation Co.	Lehi
Lehi Spring Creek Irrigation Co.	Lehi
Loafer Water Users Association	Salem
Mapleton Irrigation Co.	Springville
Matson Spring Irrigation Co.	Springville
Mitchell Hollow Irrigation Co.	Lehi
Mitchell Springs Irrigation Co.	American Fork
North Union Irrigation Co.	Orem
Payson Fruit Growers	Payson
Provo Bench Canal and Irrigation Co.	Orem
Provo Reservoir Water Users	Pleasant Grove
Salem Pond Co.	Salem
Springville Irrigation Co.	Springville
Strawberry Highline Canal Co.	Payson
Strawberry Water Users Association	Payson
Timpanogos Canal Co.	Provo
Upper East Union Irrigation Co.	Provo
Warm Springs Irrigation and Power Co.	Goshen
Wood Springs Irrigation Co.	Springville

Information gathered during field visits at potential inflow sites was evaluated with other sources of resource information including digital imagery, municipal outfall location maps, current watershed sampling locations and verbal insights from land managers, agricultural producers and water managers around Utah Lake. The comparisons and mapping exercise led to the identification of 20 sites that are contributing a significant amount of largely unmonitored water into the lake as listed in Table 16.

Potential inflow monitoring sites correspond to the points labeled on Figure 21. These sites, including the type of inflow, predominate surrounding land use, and whether monitoring is recommended is provided along with its location. The recommendations are based upon their proximity to current sampling points and potential significance in nutrient loading to Utah Lake.

Table 16. Inventory of Potential Utah Lake Inflows without regular monitoring.

Inflow ID	Description, Name, Label or Landmark	Latitude	Longitude	Type*	Land Use**	Monitoring
6	North Hunter Slough	40.212189	111.500885	D	Ag	No
7	Hunter Slough	40.211553	111.494417	D	Ag	Yes
9	Buckwalter-Brown Slough	40.202967	111.474996	D	Ag	Yes
10	Wooton Slough	40.202590	111.473436	D	Ag	No
11	Pulley Slough	40.202499	111.472388	D	Ag	No
12	Ovard Slough	40.201803	111.470879	D	Ag	No
15	Main Drain / Lindon Hollow Creek	40.200154	111.453001	E, SW	Comm / Res	No
51	Taylor Drain	40.160535	111.442768	S	Comm / Res	No
TBD	Lake Bottom Canal			I	Ag / Res	No
28	Big Dry Creek	40.122736	111.411997	D	Comm / Res	Yes
3	Carp Creek / Despain Ditch	40.150875	111.434727	SW, D	Ag / Res / Comm	No
25	Airport Moat Drain	40.135985	111.441156	R, D	Ag / Comm	Yes
26	Drain Provo Bay 1	40.122201	111.421376	D	Ag / Res	Yes
27	Drain Provo Bay 2	40.122836	111.410868	D	Ag / Res	Yes
29	Drain Provo Bay 3	40.121408	111.405303	D	Ag / Res	Yes
30	Drain Provo Bay 4	40.120154	111.402996	D	Ag / Res	Yes
39	3200 W Drain	40.092724	111.444953	R	Ag	Yes
40	4000 W Drain	40.091039	111.450229	R	Ag	Yes
45	Warm Springs	39.573752	111.512206	R, S	Ag	Yes
42	Strawberry Highline Canal Input	40.064008	111.473894	I	Ag	Yes

*** Type Key**	**** Land Use Key**
D – Drain E – Effluent I – Irrigation SW – Stormwater S - Springs R – Return flow	Ag – Agricultural Res – Residential Comm - Commercial

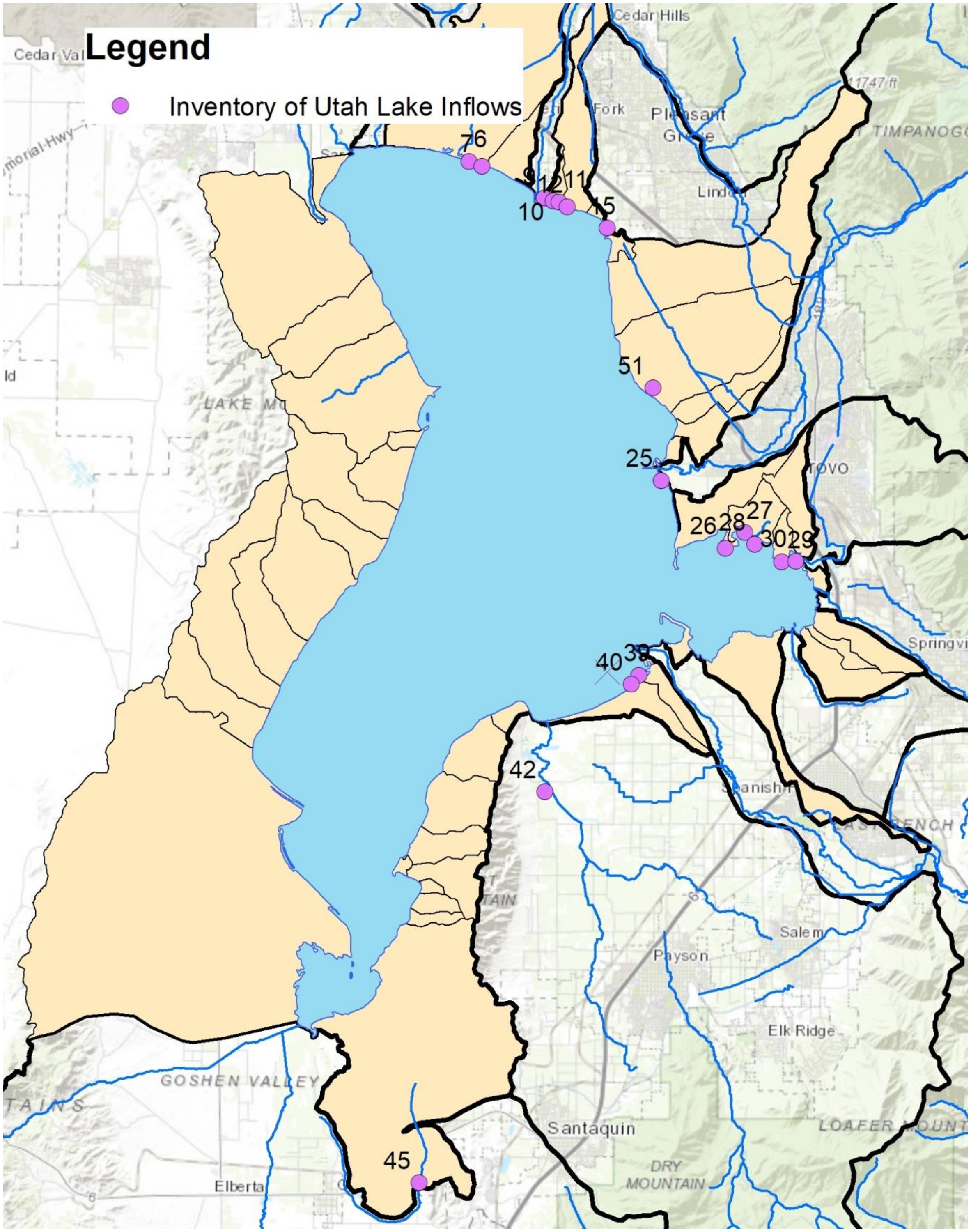


Figure 21. Inventory of Utah Lake Inflows without regular monitoring.

8.2.2 Previously Developed Water Budgets

The Utah Lake Water Quality Salinity Model (LKSIM) model developed by Dr. LaVere Merritt was used in a 2008 study of pollutant loading titled *Utah Lake TMDL: Pollutant Load Assess & and Designated Use Impairment* (Psomas, 2007). The strength of LKSIM is that it estimates monthly discharge volume for all inflows to the lake using available stream flow and precipitation data and estimates ground water and spring contributions by balancing ion concentrations in the lake. However, there are some limitations to using the LKSIM water budget for estimating the total nutrient load delivered to the lake:

- LKSIM does not account for some potentially significant hydrologic contributions like those from stormwater or from event driven discharge events.
- LKSIM estimates are based on average monthly conditions that may not accurately characterize episodic precipitation and runoff events.
- Discharge volumes for tributaries without flow data are estimated by statistical comparison to paired watersheds with available data.

The LKSIM analysis is suited for estimating average monthly discharge volumes for tributary and subsurface water delivery, but is limited in its use for evaluating tributaries independently, accounting for the unique hydrologic qualities of each. Additionally, the averaging period used in LKSIM does not allow evaluation of event driven loading events such as significant runoff or drought conditions.

Other hydrologic analyses have been conducted previously on Utah Lake primarily for the purpose of water management activities associated with the Central Utah Project and management of downstream water rights. These include the State Water Plan for Utah Lake Basin, the Utah Lake System EIS, and the Utah Lake Comprehensive Management Plan (DWQ, 2008). While these analyses are useful for water management of Utah Lake they are not of sufficient resolution for use in estimating nutrient loading and are not considered further in this report.

The Phase 1 recommendation for improving the LKSIM water budget is to establish high frequency monitoring stations on significant tributaries. The produced dataset will improve site specific understanding of flow conditions, more accurately account for unique water management activities in each, and provide finer temporal resolution to more accurately characterize dynamic hydrologic conditions.

8.2.3 Water Budget Data Characterization

Flow information for the Utah Lake watershed includes discrete “grab sample” measurements and continuous flow measurements. Grab sample, or instantaneous flow measurements, are usually recorded when water samples for laboratory analysis are collected. As a result, instantaneous flow measurements represent flow conditions at a specific point in time. Real-time flow measurements, otherwise known as continuous flow, are collected by a high frequency monitoring device capable of providing hourly or daily flow values.

DWQ evaluated locations and sample frequency for instantaneous and continuous flow measurements in proximity to Utah Lake. Based on guidance from stakeholders monitoring locations were evaluated for representativeness of upstream land uses and their ability to characterize loading and flow conditions for watersheds with limited data and information.

8.2.3.1 Continuous Flow

The U.S. Geological Survey (USGS) maintains most of the continuous flow monitoring stations surrounding Utah Lake (Table 17 and Figure 22) including three significant tributaries (Provo River, Hobble Creek, and the Spanish Fork River). Data available for each location includes hourly flow and stage measurements as well as average daily flow. The Spanish Fork river location (10150500) was discontinued in 1988 and is no longer active. A second USGS gage on the Spanish Fork River, located near Castilla, UT, is above the mouth of Spanish Fork Canyon and the diversion to the Strawberry Highline Canal system. This location cannot be used to estimate flow volume delivered to the lake.

Table 17. USGS Flow Gages in Proximity to Utah Lake with Sub-daily and Average Daily Discharge.

Site Number	Site Name	Longitude	Latitude	Status	Start Date	End Date
10146000	Salt Creek At Nephi, UT	-111.8043759	39.71301186	Active	1950	Current
10146400	Currant Creek Near Mona, UT	-111.8629909	39.80245444	Active	1978	Current
10147100	Summit Creek Abv Summit Cr Canal Nr Santaquin UT	-111.7748889	39.9444722	Active	2015	Current
10150500	Spanish Fork At Castilla, UT	-111.5479705	40.0496781	Active	1919	Current
10152000	Spanish Fork Near Lake Shore, Utah	-111.7260394	40.15023176	Inactive	1904	1988
10153100	Hobble Creek At 1650 West At Springville, Utah	-111.639338	40.1788719	Active	2008	Current
10163000	Provo River At Provo, UT	-111.69937	40.2377318	Active	1903	Current
10164500	American Fk Ab Upper Power plant Nr American Fk, UT	-111.6821472	40.4477297	Active	1927	Current

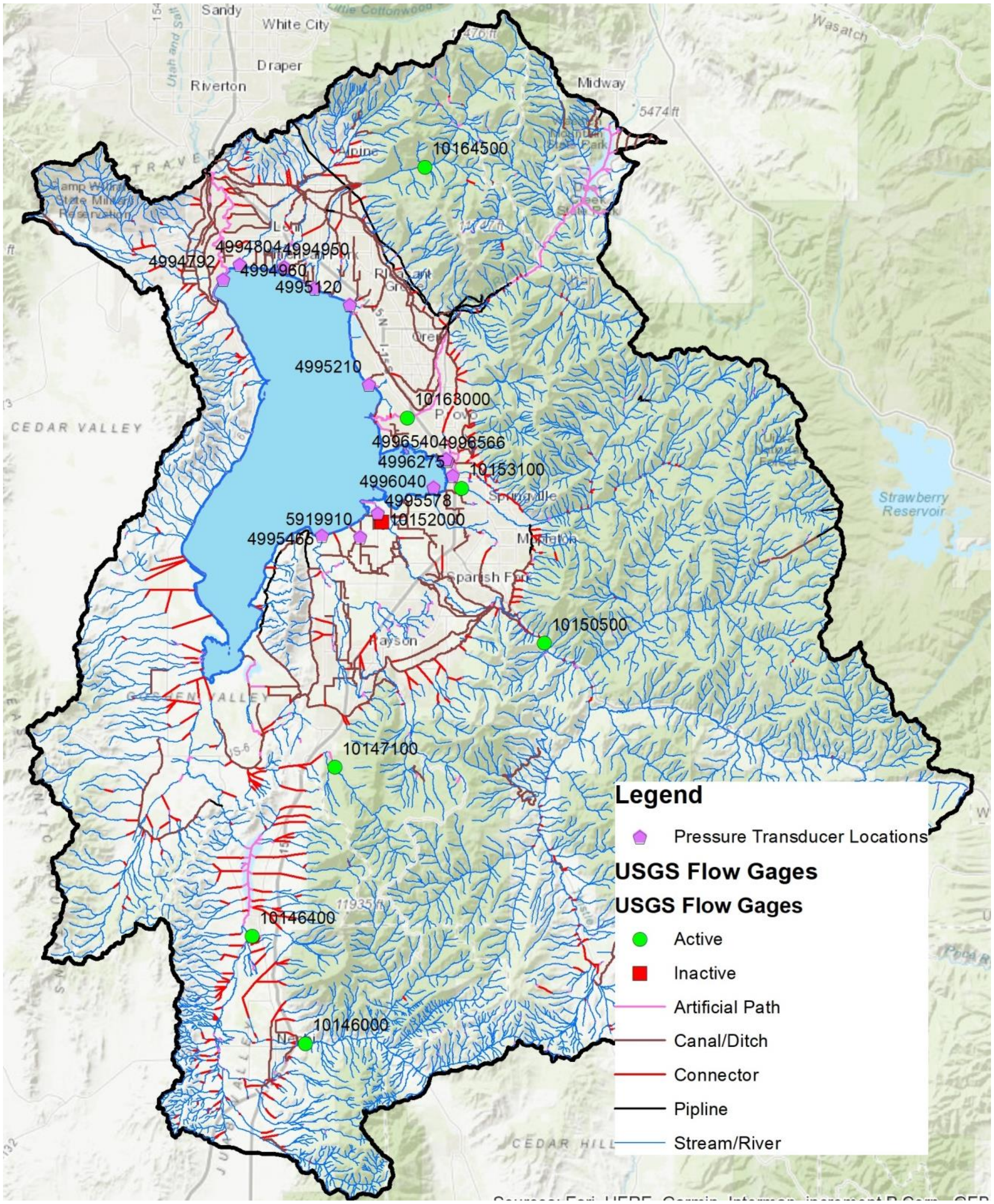


Figure 22. Active and Inactive USGS Gages and Pressure Transducer Locations in Proximity to Utah Lake.

8.2.3.2 Pressure Transducer Monitoring of Continuous Flow

DWQ installed a network of continuous flow monitoring pressure transducer stations in 2017 to supplement the USGS continuous flow network and instantaneous monitoring stations (Figure 22 and Table 18). Transducers are programmed to record water depth, pressure, and water temperature at 15 minute intervals. To determine discharge, a relationship between flow and water depth is developed by pairing readings of measured instantaneous flow with the corresponding measurement of stage recorded on the pressure transducer. These paired measurements are then plotted to develop a discharge rating curve. Once a statistically significant relationship is developed, pressure transducer stage measurements can be used to determine discharge at frequent time steps. For the pressure transducers located around Utah Lake, discharge is measured at a 15 minute interval, which greatly improves data resolution over instantaneous flow values.

Table 18. Pressure Transducer Flow Monitoring Locations.

MLID	Site Name	Latitude	Longitude
4995465	Benjamin Slough at Utah Lake	40.138413	-111.793596
4995578	Spanish Fork River At Utah Lake Inlet	40.167158	-111.750213
4996040	Dry Ck Near Utah Lake	40.181488	-111.671552
4996275	Spring Creek At I-15 Frontage Road	40.189569	-111.648969
4996566	Mill Race Creek (South) below I-15	40.201905	-111.654758
4996540	Mill Race Creek (North) below I-15	40.203113	-111.656176
4995210	Powell Slough North Outfall To Utah Lake	40.265157	-111.742768
4994960	American Fk Ck 2.5Mi S Of Am Fk City	40.343796	-111.801778
4994950	Spring Ck Bl Lehi Mill Pond	40.363049	-111.835150
4994804	Dry Creek At 145 N (Saratoga Springs)	40.365040	-111.883930
4994792	Saratoga Springs At Cedar Valley	40.352421	-111.901945
4995120	Lindon Drain At Co Rd Xing Ab Utah Lake	40.331923	-111.763062
5919910	Drain At 4000W	40.137179	-111.749380

8.2.3.3 Instantaneous Flow

The primary source of instantaneous flow data for Utah Lake tributaries is available from the DWQ Ambient Water Quality Monitoring System database (AWQMS) and was provided by a number of partner agencies during sampling of water quality chemistry parameters. More than 400 historic and current monitoring locations exist in the Utah Lake watershed. As described in the Data Management and Compilation section of this document, DWQ and partners implemented a monitoring plan in 2017 of all major tributary watersheds around the lake.

Table 19 lists these locations and summary statistics for instantaneous flow data available at each location. Figure 3 shows the locations of all instantaneous flow and water quality monitoring stations included in DWQ's 2017 and 2018 Sampling and Analysis Plan. Figure 23 shows summary statistics for instantaneous flows collected during routine water quality monitoring.

Table 19. Monitoring Locations with Instantaneous Flow Measurements.

Watershed	Monitoring Location ID	Monitoring Location Name	Start Date	End Date	Count	Min (cfs)	Mean (cfs)	Max (cfs)
Direct Drainages								
Spring Creek - Lehi	4994950	Spring Ck Bl Lehi Mill Pond	1/24/78	1/10/18	67	0.5	12.3	96.3
Timp. SSD	4995038	Timpanogos Effluent Below Constructed Duck Ponds	3/4/80	1/10/18	267	0.3	10.2	41.85
Major Tributaries								
Hobble Creek	4996100	Hobble Ck At I-15 Bdg 3Mi S Of Provo	9/8/82	8/7/17	195	0	60.2	650
Benjamin Slough	5919850	Benjamin Slough At 6400 South	3/7/09	12/28/10	16	14	42.1	100
	4995465	Benjamin Slough above Utah Lake	6/4/86	1/10/18	74	0	33.0	150
Mill Race	4996540	Mill Race North Below I-15	8/21/85	1/10/18	100	0	32.8	75.6
	4996630	Mill Race Creek At Mouth	1/12/00	1/11/06	6	2.6	28.6	38.8
	4996566	Mill Race South Below I-15	5/12/17	1/10/18	9	7.216	16.5	26.434
American Fork River	4994960	American Fk Ck 2.5Mi S Of Am Fk City	10/25/90	11/7/17	69	0	25.4	370
Powell Slough	4995210	Powell Slough Wma North Outfall To Utah Lake	5/20/76	11/8/17	257	0.9	10.3	99.9
	4995230	Powell Slough Wma South Outfall To Utah Lake	4/8/04	11/8/17	15	0.5	3.4	6
Currant Creek	4995310	Currant Ck At Us6 Xing 1.5Mi W Of Goshen	2/12/92	9/13/17	37	0	5.1	35.44
Spanish Fork River	4995580	Spanish Fork R Ab Utah L (Lakeshore)	5/26/76	8/3/13	114	0	154.9	1150
	4995578	Spanish Fork River Above Utah Lake	5/12/17	1/10/18	5	50.25	141.4	326.8
Provo River	4996680	Provo River At Cntr St. Bridge	9/13/90	10/25/90	2	5	16.0	27
Lindon Drain	4995120	Lindon Drain At Co Rd Xing Ab Utah Lake	3/17/94	9/14/17	100	0.25	21.8	135
	4995123	Lakeside Power Plant 001	10/28/09	5/14/12	15	0	481.6	844.6
Dry Creek - Spanish Fork	4996040	Dry Ck Near Utah Lake-WLA	6/12/17	11/8/17	5	19.393	41.1	97.5
Saratoga - Tickville	4994792	Saratoga Springs At Cedar Valley	5/16/17	1/10/18	7	0.5	19.6	28.633
Dry Creek - Saratoga	4994804	Dry Creek At 7350 N (Saratoga Springs)	5/16/17	1/10/18	4	2.26	14.3	29.088
Spring Creek - Provo	4996275	Saratoga Springs At Cedar Valley	10/9/17	1/10/18	4	19.748	25.2	39.6

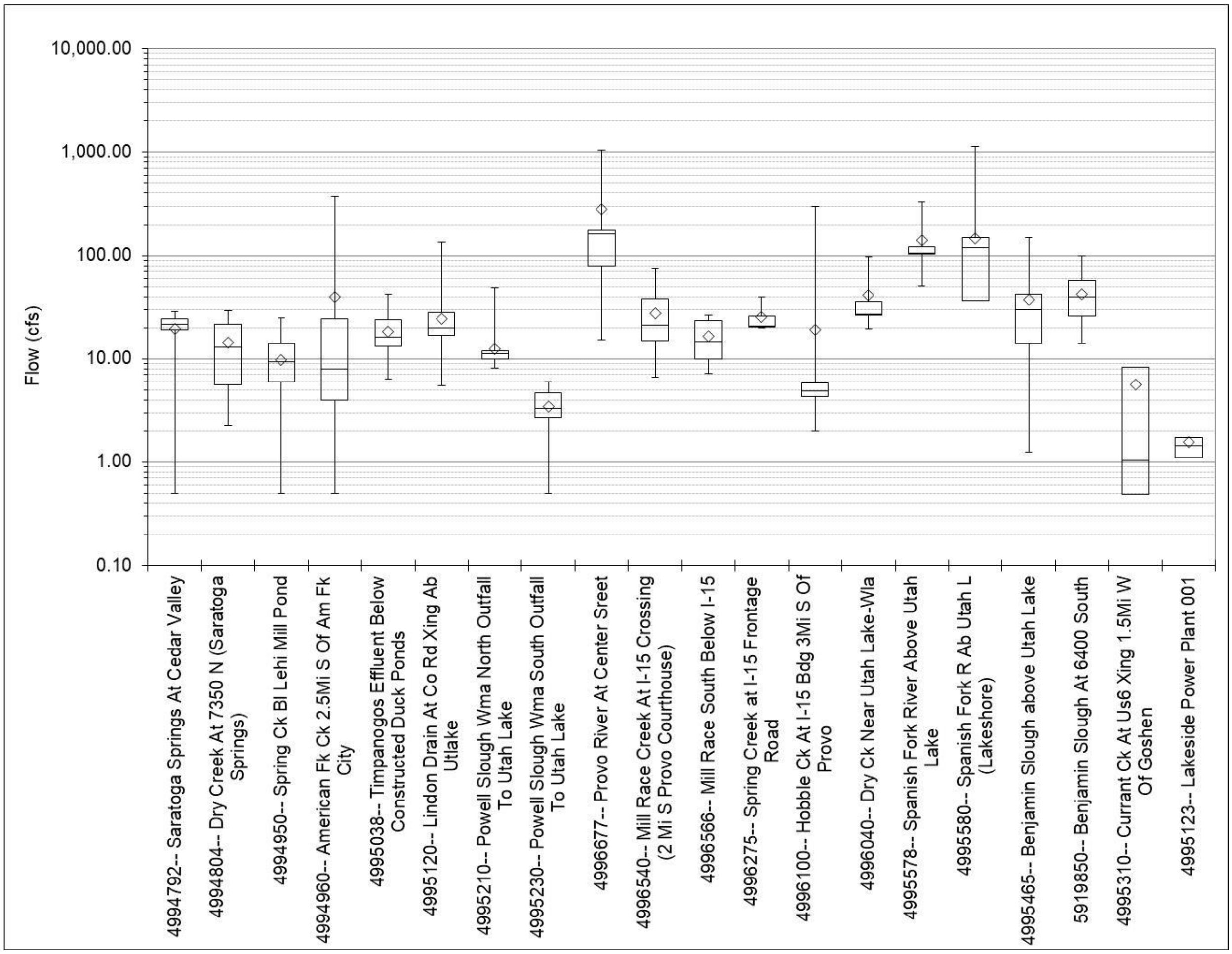


Figure 23. Summary statistics for instantaneous flow measurements at locations in proximity to Utah Lake.

8.3 Bulk Nutrient Loading

8.3.1 Utah Lake Pollutant Load Assessment Report

The *Utah Lake TMDL: Pollutant loading Assessment report* (DWQ, 2008) presents the most current nutrient loading assessment for the lake. The approach for this analysis first estimates the total water budget to the lake from all major flow contributions including major tributaries, precipitation, springs, ground water, and publicly owned treatment works (POTWs) using the previously discussed LKSIM water budget. Second, average nutrient concentrations were calculated based on existing water chemistry data for each flow contribution type. Finally, flow and concentration data and the appropriate conversion factors were combined to produce the estimated total nutrient load to the lake.

This analysis uses the LKSIM water budget as a foundation, which allows for estimating nutrient loading from all sources contributing water to the lake. This approach also reasonably characterizes average monthly nutrient loads from each of these sources. There are however several limitations and assumptions to this approach being considered in ongoing monitoring and research efforts:

- Load estimates represent average monthly conditions and do not account for the influence of significant hydrologic events like drought, extreme high- and low-flow events, precipitation driven events, and other significant hydrologic factors.

- Monitoring locations for some tributaries do not represent conditions at the location where the tributary enters the lake. This may not account for nutrient cycling within the stream, localized land management activities, and major hydrologic changes occurring near the lake.

- Sources originating in direct drainage watersheds like stormwater runoff and agricultural irrigation return flow are not well characterized. Estimates for these sources are incorporated in the load analysis since all sources of water are characterized and assigned an average concentration. However, stormwater and agricultural sources are highly influenced by discrete hydrologic events and the method used in this analysis likely does not accurately characterize them

- Nutrient loads delivered directly to the lake from land management activities below the high water line, ungaged tributaries, and atmospheric deposition are not accounted for.

These considerations were generated by stakeholders at the beginning of the Phase 1 effort and are being addressed by ongoing monitoring, research, and watershed modeling efforts being conducted by DWQ, University of Utah, and other partner entities.

8.3.2 Loading Data Characterization

Paired samples of flow and nutrient concentrations are required to calculate loading at a sampling location. It is important to note that flow data is not always available for a given water chemistry sample, prohibiting the calculation of load for that respective sample. Table 20 summarizes sample counts for nutrient parameters and flow for computing loads delivered to the lake from locations in closest proximity. To be consistent with the ongoing water quality modeling effort being conducted by the University of Utah this discussion will focus on data collected from 2005 to present.

The data represented in Table 20 was predominately collected by DWQ, the Wasatch Front Water Quality Council (WFWQC), and BYU with the express purpose of characterizing inflow conditions, however, much of the data collected in 2016 is flagged for quality control purposes:

1. Data collected by the WFWQC are flagged as provisional and incomplete. Some locations show a sample count of zero for flow data because the data was not received by DWQ. Additionally, 2017 data was not submitted to DWQ for inclusion in this analysis.

2. 2016 and 2017 DWQ samples represent provisional samples as they undergo QA/QC analysis.

Generally, Table 20 shows there is a good amount nitrogen and phosphorus data available for updating load estimates to the lake. Larger tributaries such as the Provo River, Spanish Fork River, Hobble Creek, Benjamin Slough, American Fork River, and Powell slough have good data richness while others have limited data since they only began to be sampled recently.

Table 20. Count of Nutrient Parameters for Estimating Nutrient Loading to Utah Lake.

Watershed	MLID	Monitoring Location Name	Start Date	End Date	Flow (n)	NO23 (n)	Ortho P (n)	TP (n)	TKN (n)	TN (n)	TOC (n)	TON (n)
Direct Drainages												
Timp SSD	4995038	Timpanogos Effluent Below Constructed Duck Ponds	1/26/2005	1/10/2018	85	18	0	173	5	85	33	4
	4995041	Timponogos SSD Tributary	5/16/2017	11/6/2017	0	14	0	14	0	16	22	0
	UL04	Ul04 Timpanogos @ Mouth	10/14/2015	6/7/2017	0	16	16	30	16	16	0	0
Major Tributaries												
4000 West Drain	5919910	Drain 4000 West and 5000 S	10/14/2015	6/16/2017	0	17	17	34	17	17	0	0
American Fork River	4994960	American Fk Ck 2.5Mi S Of Am Fk City	4/18/2006	11/7/2017	49	18	12	125	12	62	18	1
Benjamin Slough	5919850	Benjamin Slough At 6400 South	3/7/2009	12/28/2010	16	0	0	48	0	23	5	1
	4995465	Benjamin Slough above Utah Lake	4/14/2010	1/10/2018	38	35	19	109	19	64	25	0
Currant Creek	4995310	Currant Ck At Us6 Xing 1.5Mi W Of Goshen	10/27/2009	12/6/2017	25	12	0	60	0	36	6	0
Dry Creek - Saratoga	4994804	Dry Creek At 7350 N (Saratoga Springs)	5/16/2017	1/10/2018	4	8	0	8	0	8	14	0
Dry Creek - Spanish Fork	4996040	Dry Ck Near Utah Lake-WLA	10/3/2012	11/8/2017	5	12	0	18	3	15	14	0
Hobble Creek	4996100	Hobble Ck At I-15 Bdg 3Mi S Of Provo	1/25/2005	1/10/2018	62	37	19	186	19	90	34	1
Lindon Drain	4995075	Ul05 Battle Creek @ Mouth	10/14/2015	6/7/2017	0	13	14	28	14	13	0	0
	4995120	Lindon Drain At Co Rd Xing Ab Utah Lake	1/26/2005	12/6/2017	60	14	0	136	0	63	16	1
	4995123	Lakeside Power Plant 001	10/28/2009	5/14/2012	15	0	0	38	0	19	0	0
Mill Race	4996540	Mill Race Creek At I-15 Crossing (2 Mi. S Provo Courthouse)	4/27/2005	1/10/2018	19	34	14	70	14	34	26	0

Watershed	MLID	Monitoring Location Name	Start Date	End Date	Flow (n)	NO23 (n)	Ortho P (n)	TP (n)	TKN (n)	TN (n)	TOC (n)	TON (n)
	4996630	Mill Race Creek At Mouth	10/14/2015	6/16/2017	2	0	0	0	0	0	0	0
	4996565	Provo Station 5-Wla	10/22/2014	11/11/2014	0	0	0	4	2	3	0	0
	4996566	Mill Race South Below I-15	10/22/2014	1/10/2018	9	34	14	52	16	37	26	0
	MR2	Mill Race @ Mouth	10/14/2015	6/16/2017	0	12	12	24	12	12	0	0
	UL12	Ul12 Spring Creek Abv 1650 W	10/16/2015	6/7/2017	0	16	17	34	16	16	0	0
Powell Slough	4995210	Powell Slough Wma North Outfall To Utah Lake	1/26/2005	11/8/2017	56	20	6	126	15	55	23	3
	4995230	Powell Slough Wma South Outfall To Utah Lake	2/8/2005	11/8/2017	6	6	0	9	0	6	6	0
	4995258	Powell Slough Site 3-Wla	9/16/2014	9/25/2014	0	0	0	4	2	2	0	0
	4995259	Powell Slough Tributary 4-Wla	9/16/2014	9/25/2014	0	0	0	4	2	2	0	0
Provo River	4996680	Provo River At Cntr St. Bridge	10/14/2015	6/7/2017	0	17	17	34	17	17	0	0
	4996677	Provo River At Center St.	5/12/2017	1/10/2018	0	20	0	20	0	20	26	0
Saratoga – Tickville Gulch	4994792	Saratoga Springs At Cedar Valley	5/16/2017	1/10/2018	7	14	0	14	0	16	22	0
Spanish Fork River	4995580	Spanish Fork R Ab Utah L (Lakeshore)	1/26/2005	8/3/2013	49	0	0	157	0	51	8	5
	4995578	Spanish Fork River Above Utah Lake	10/14/2015	1/10/2018	5	36	18	54	18	38	26	0
Spring Creek - Lehi	4994950	Spring Ck Bl Lehi Mill Pond	3/5/2009	1/10/2018	56	20	0	125	0	70	34	1
	UL01	Ul01 Spring Creek Upstream (Lehi)	8/21/2014	6/7/2017	0	16	16	37	16	21	0	0
	UL02	Ul02 Spring Creek Downstream (Lehi)	10/14/2015	6/7/2017	0	15	15	30	15	15	0	0
Spring Creek - Provo	4996275	Saratoga Springs At Cedar Valley	9/18/2017	1/10/2018	4	10	0	10	0	10	10	0

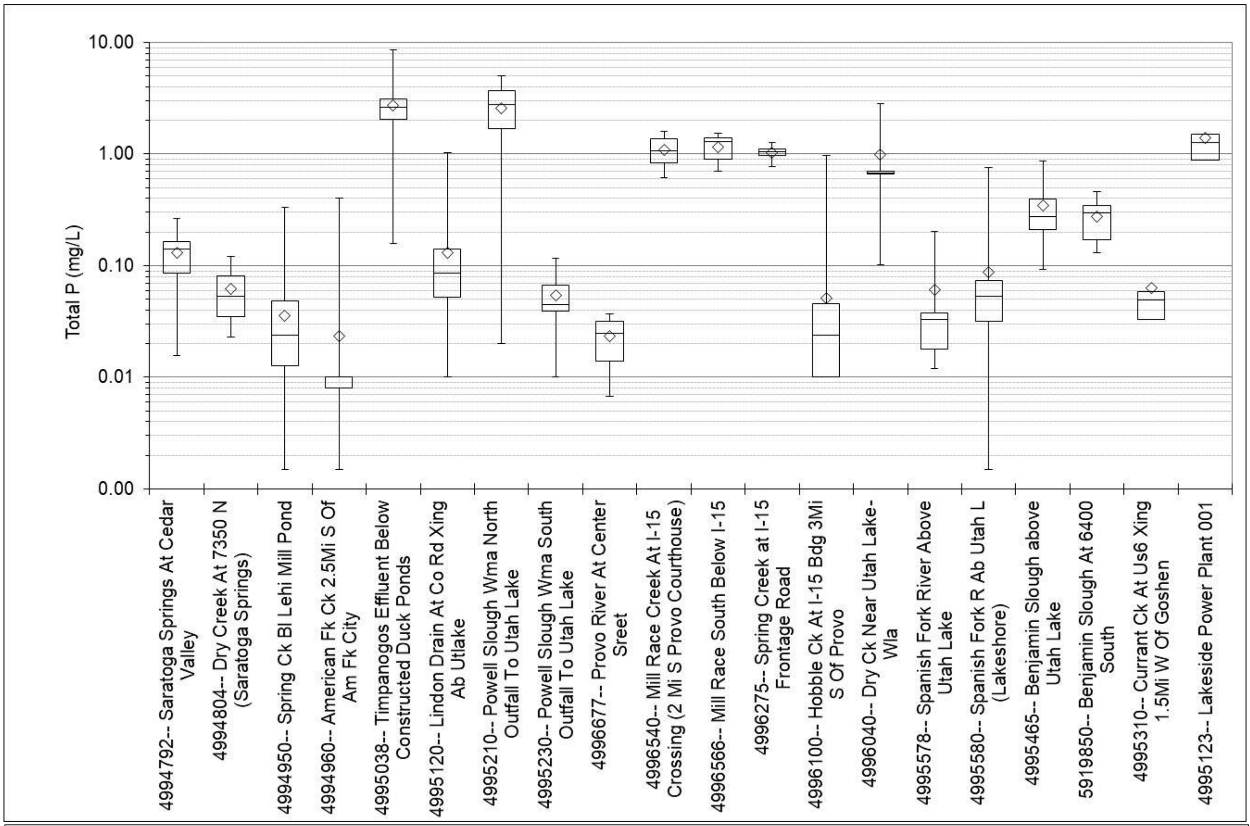
Section 8.4, below, discusses the ongoing University of Utah modeling effort and how a series of watershed models will be linked to generate nutrient loads delivered to the lake. The model frame work will be calibrated to the period of 2005 to 2015 while incorporating new data for validation and improving model performance.

These results are presented to characterize general loading conditions observed by ongoing monitoring activities. This data will be utilized by the University of Utah to characterize nutrient inputs to the lake and calibrate a series of water quality models. This is discussed in more detail the section Watershed Model Development.

Monitoring locations within the Utah Lake watershed were reviewed to identify locations that accurately reflect conditions as tributaries enter the lake. Figure 24 through Figure 31 show paired concentrations and loading for total phosphorus (TP), total nitrogen, dissolved phosphorus, total dissolved nitrogen, nitrate plus nitrite, ammonia, total organic carbon, and dissolved organic carbon. These plots represents the daily load for each location, calculated by pairing instantaneous flow and water quality samples that are scaled up to represent the total load delivered for the day.

Figure 24 shows the total phosphorus concentrations and loading associated with these locations. Figure 24 shows that Lindon Drain, Powell Slough North, Mill Race, and Dry Creek (Provo Bay) have relatively high Total Phosphorus loads as compared to smaller tributaries like the American Fork River, Powell Slough South, and Hobble Creek. The Provo River and Spanish Fork River deliver a combined 60% of inflows to Utah Lake, however, they deliver a relatively low TP load given their lower concentrations. Dissolved phosphorus concentrations and loads show a similar pattern to total phosphorus (Figure 25).

The Total Nitrogen (TN) dataset does not have as many samples as TP because the capability to analyze for TN is relatively new. TN was added to the Utah Lake monitoring program in 2017 and is sampled monthly along with TP. Daily TN loads are presented in Figure 26, with a similar trend to TP loading. Figure 27, Figure 28, Figure 29 show concentrations and loads for total dissolved nitrogen, nitrate plus nitrite, and ammonia, respectively. Figure 30 and Figure 31 show concentrations and loads for total organic carbon and dissolved organic carbon, respectively.



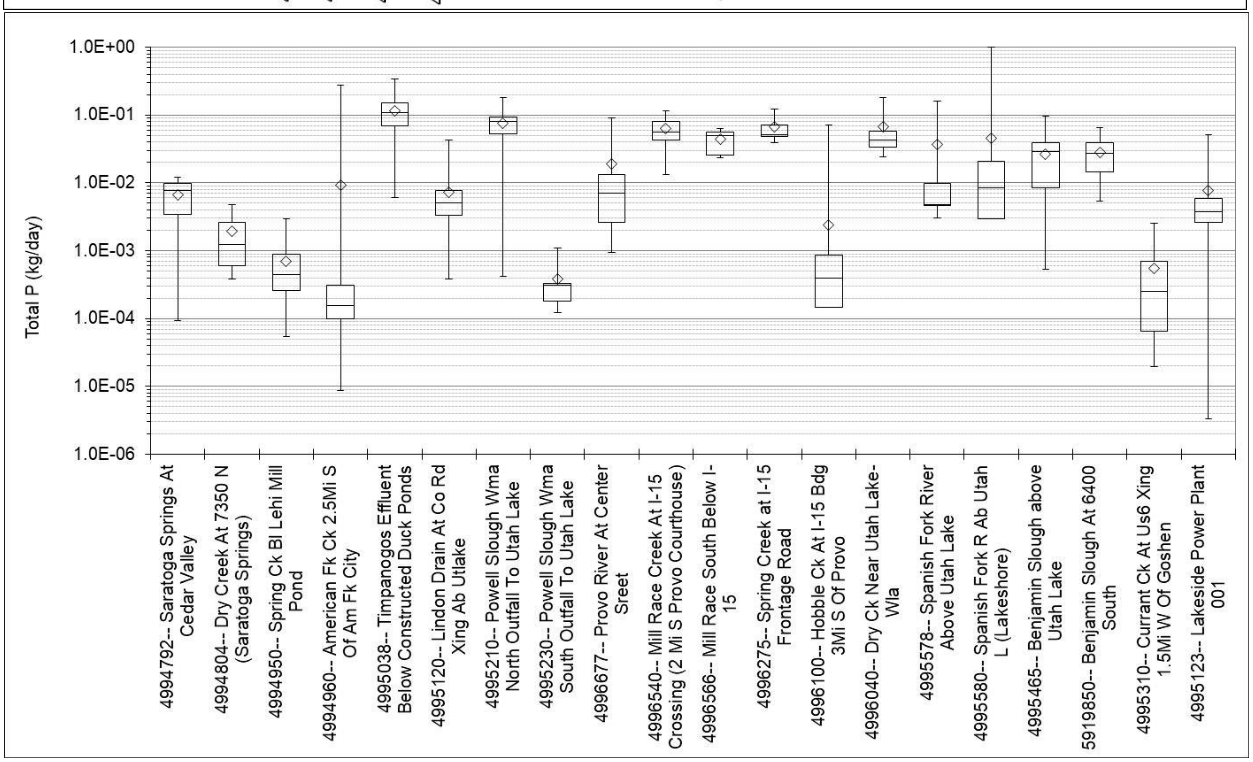


Figure 24. Total Phosphorus Concentrations and Loads from Utah Lake Tributaries.

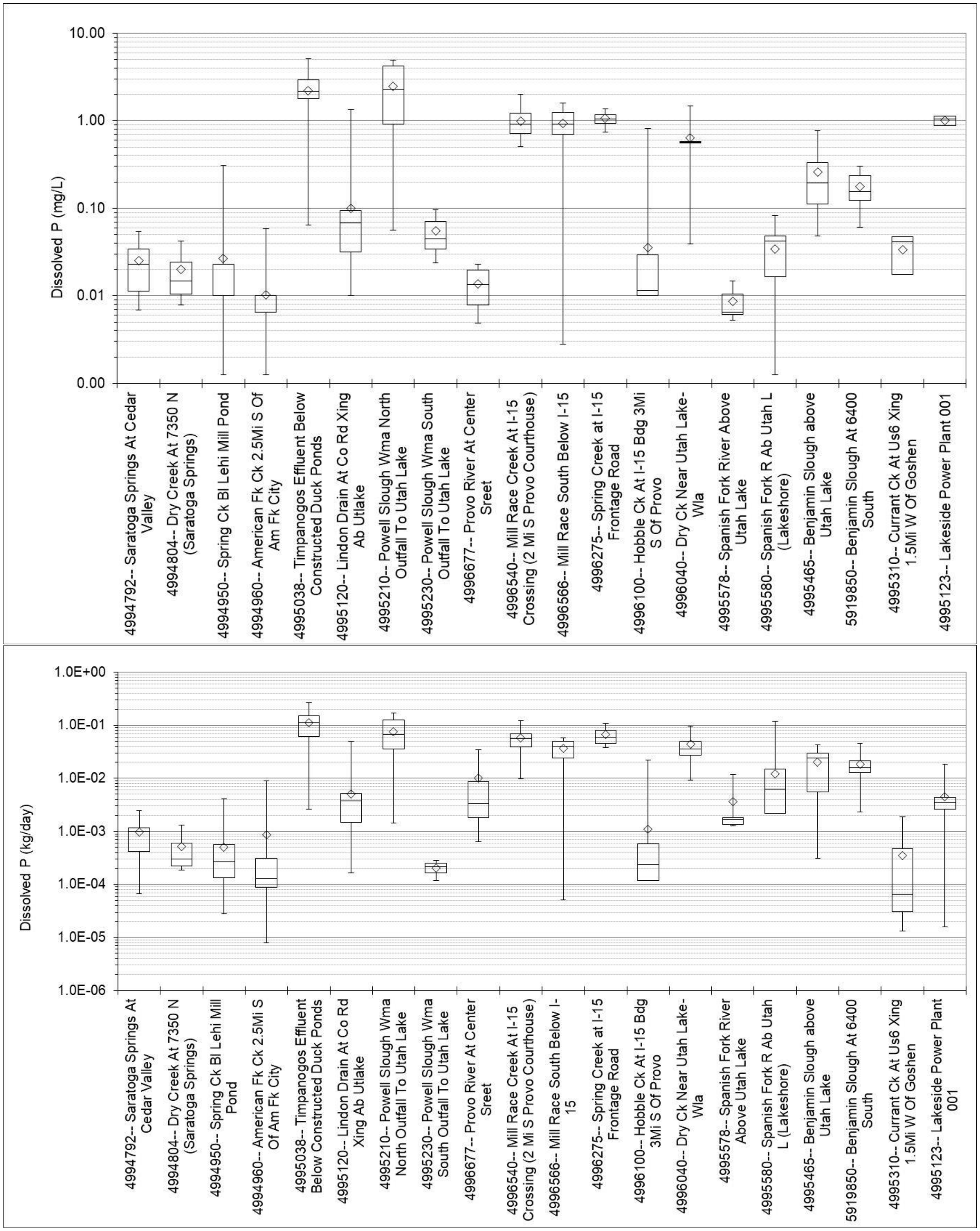


Figure 25. Dissolved Phosphorus Concentrations and Loads from Utah Lake Tributaries.

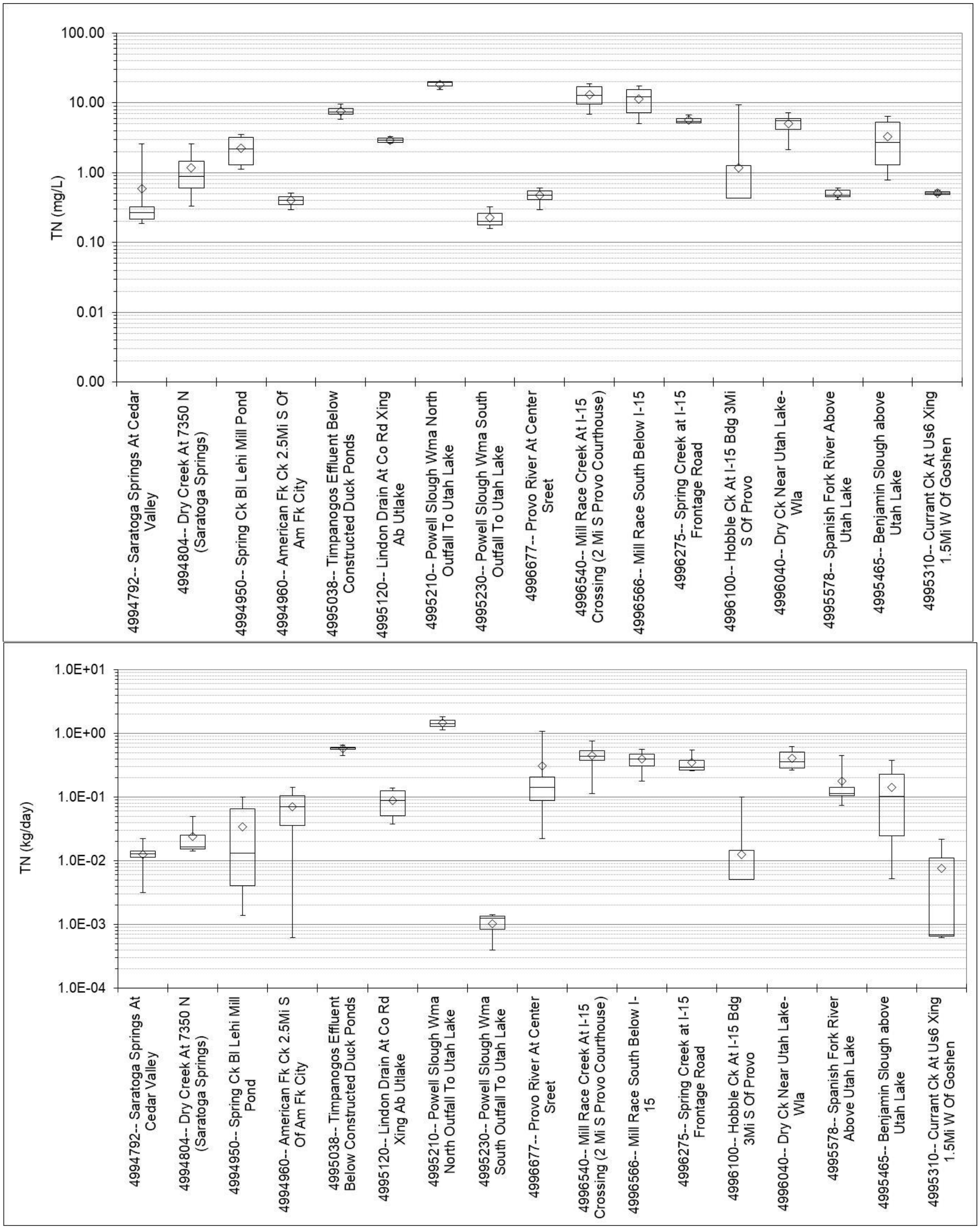


Figure 26. Total Nitrogen Concentrations and Loads from Utah Lake Tributaries.

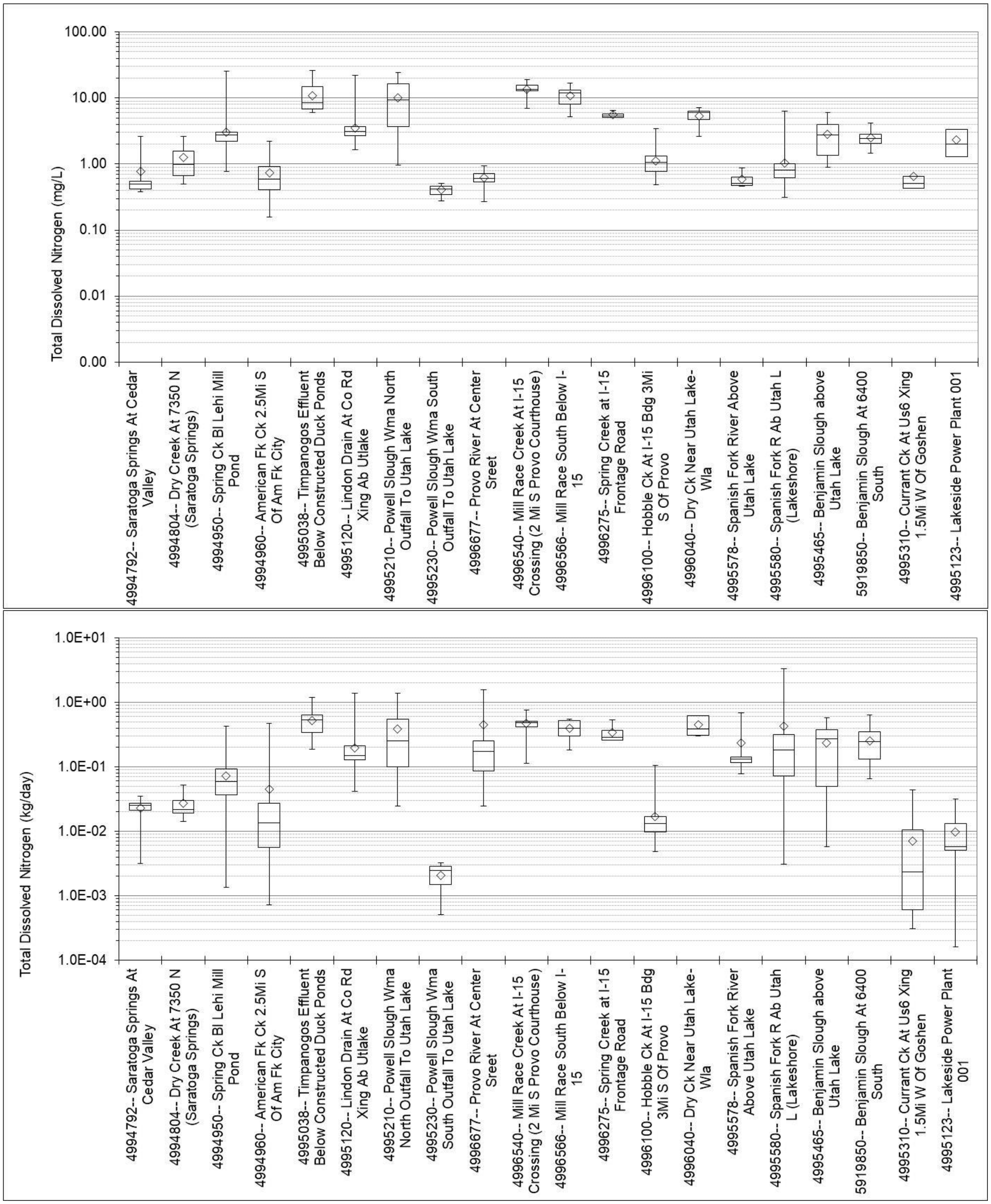


Figure 27. Total Dissolved Nitrogen Concentrations and Loads from Utah Lake Tributaries.

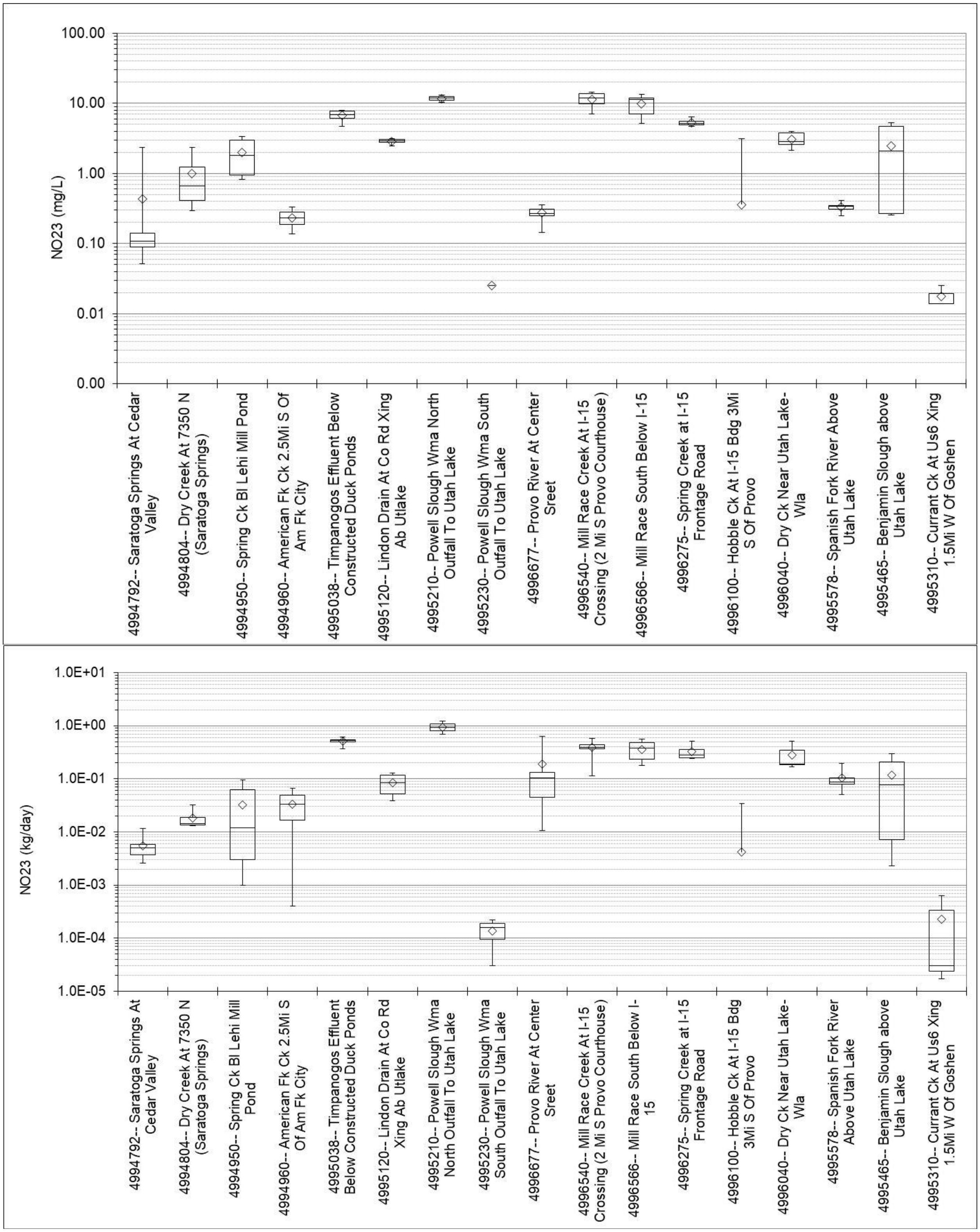


Figure 28. Nitrate Plus Nitrite Concentrations and Loads from Utah Lake Tributaries.

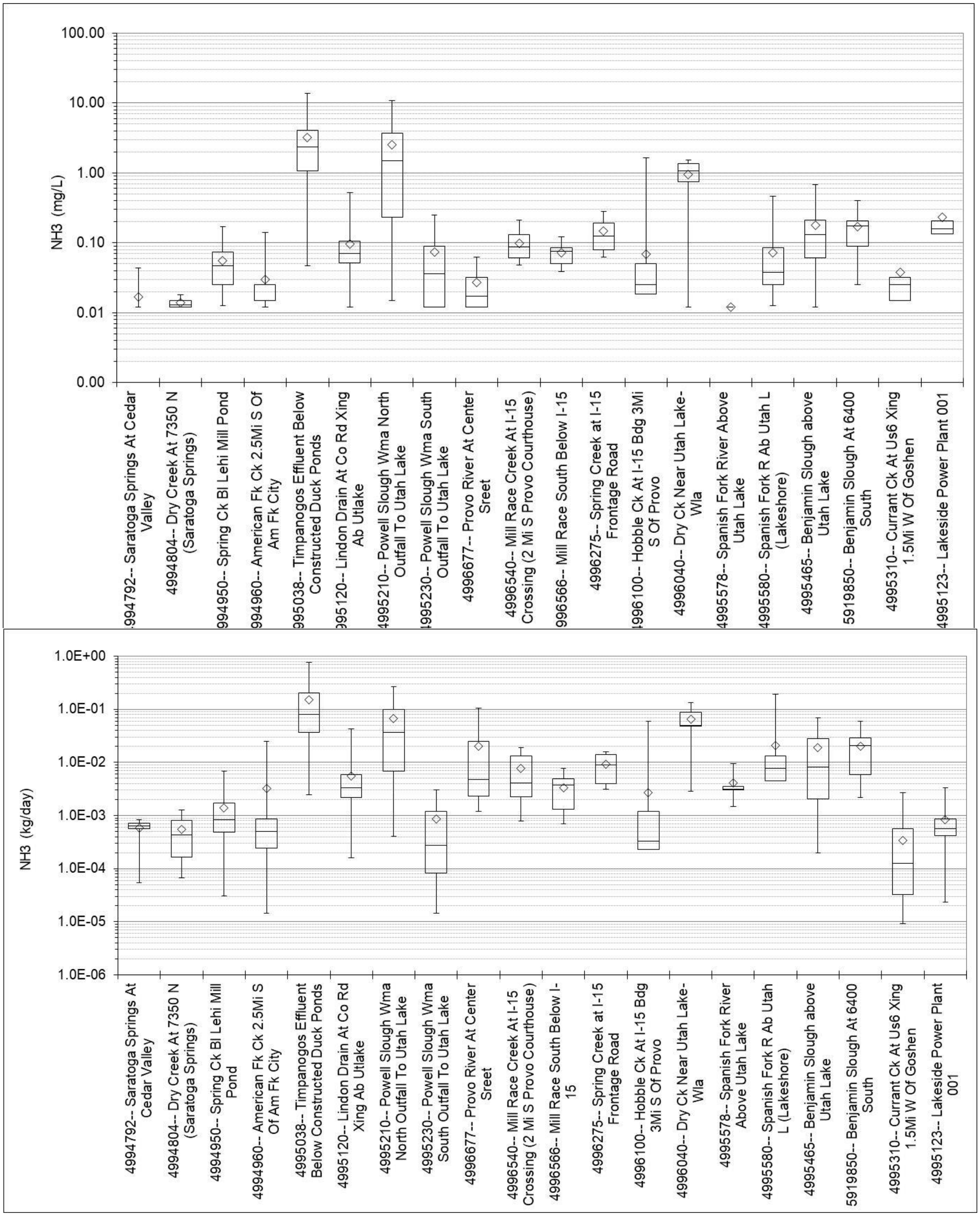
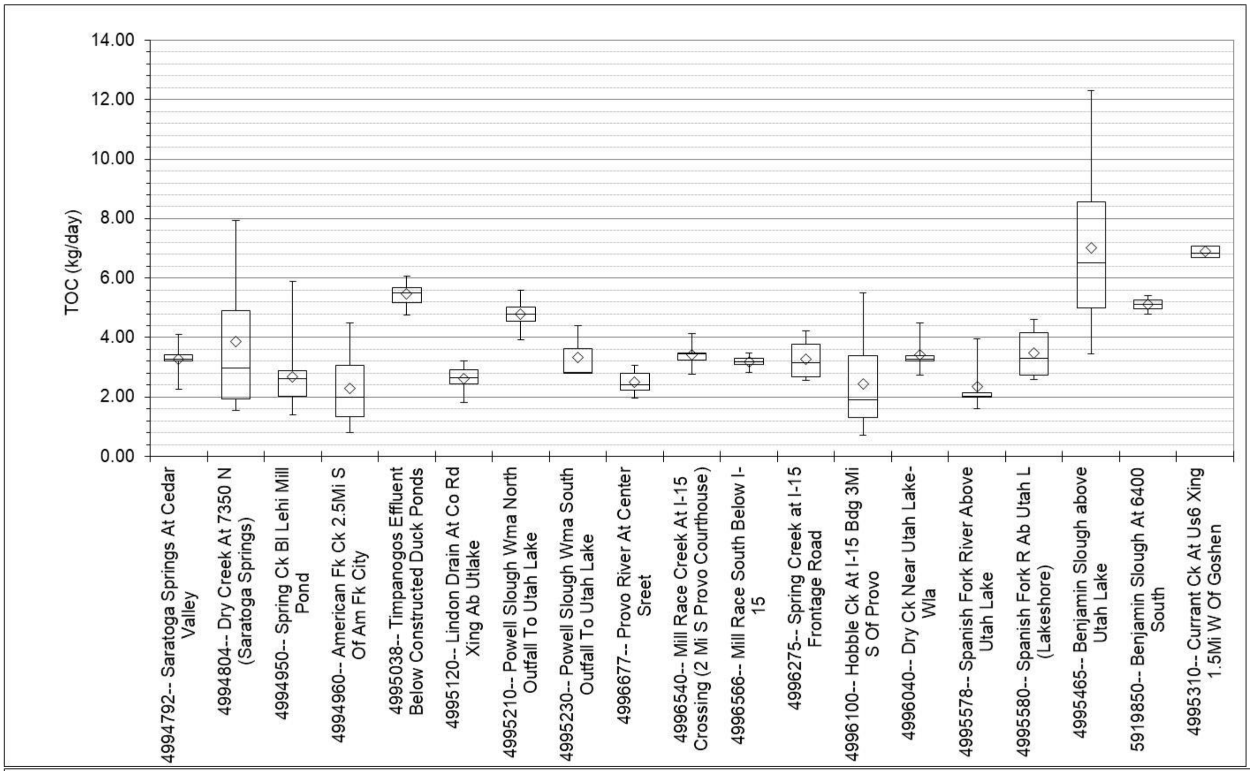


Figure 29. NH3 Concentrations and Loads from Utah Lake Tributaries.



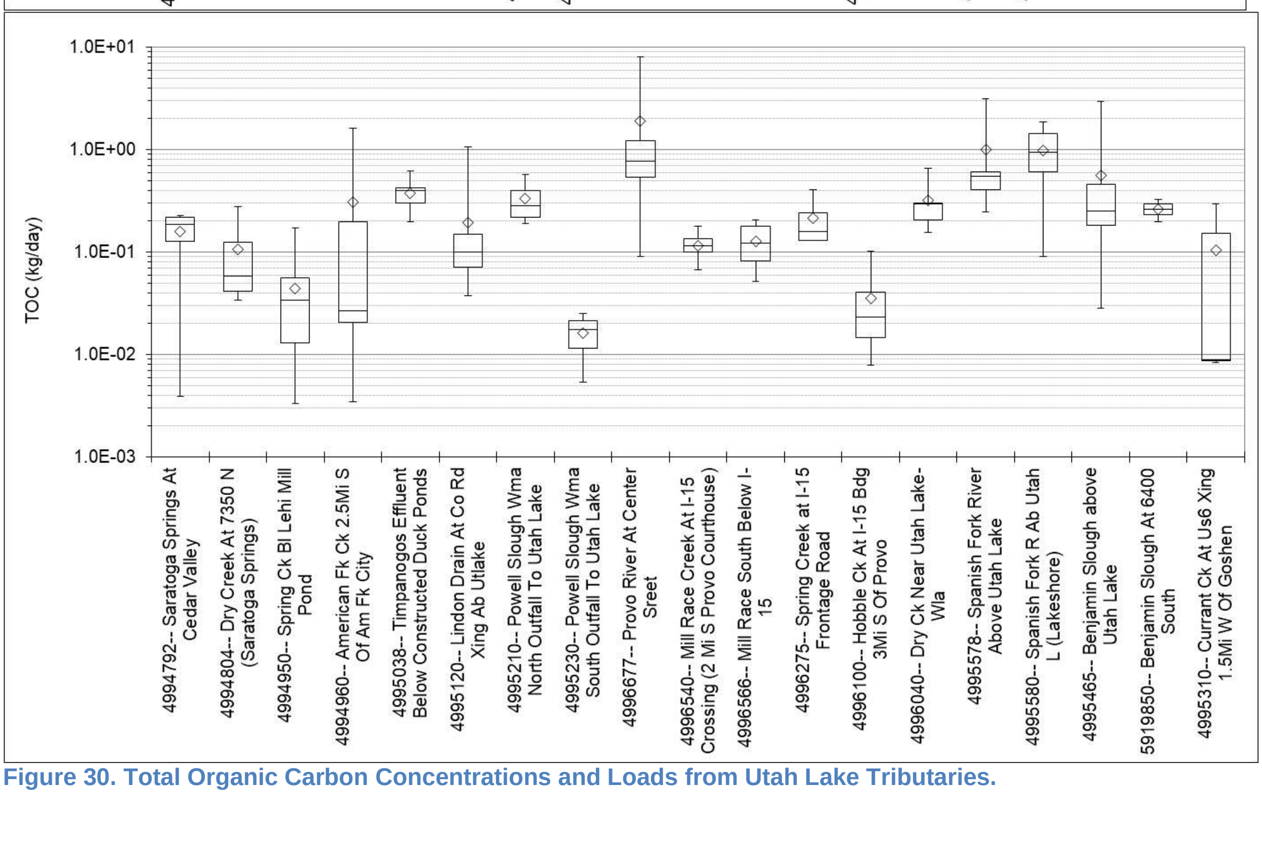


Figure 30. Total Organic Carbon Concentrations and Loads from Utah Lake Tributaries.

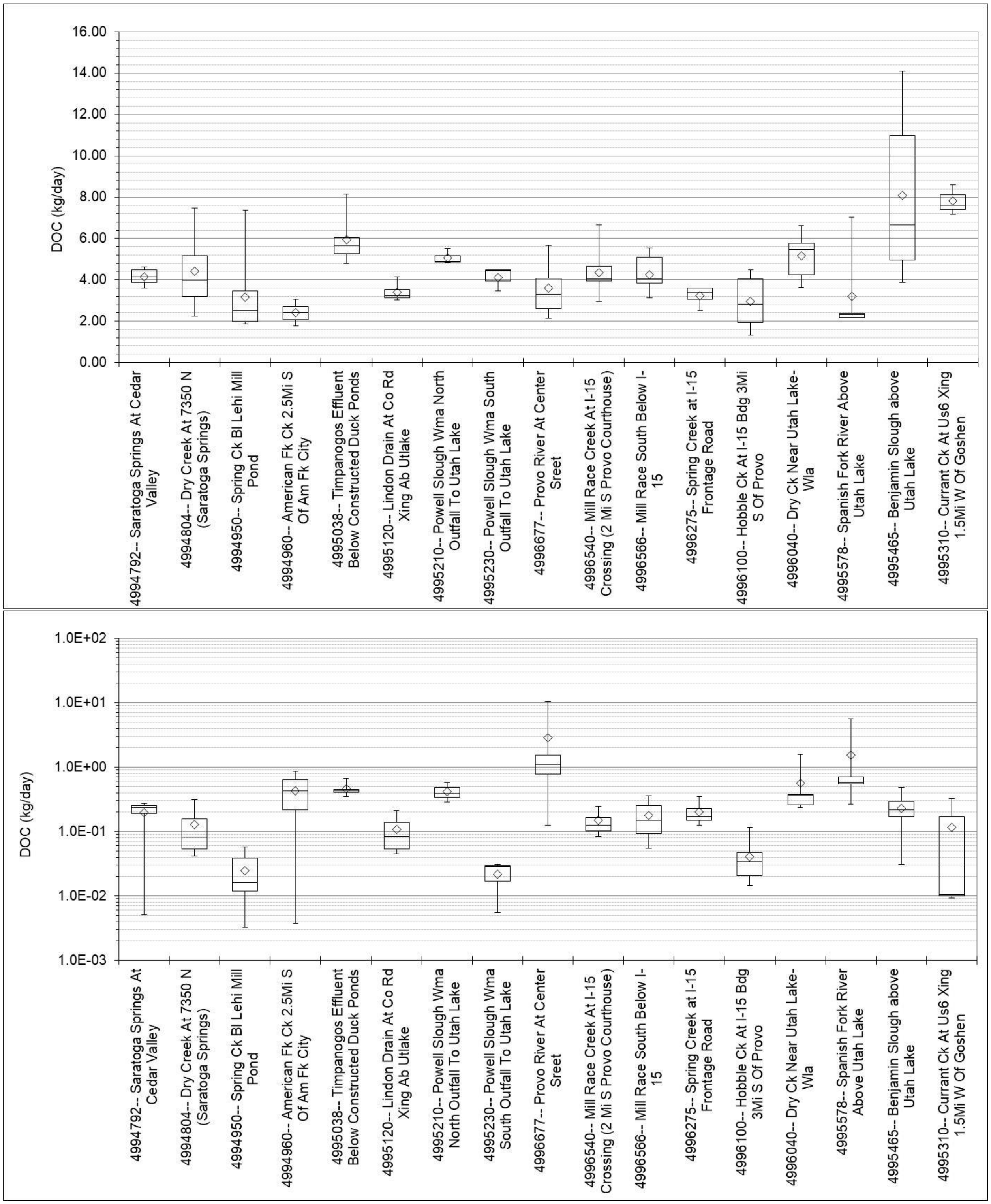


Figure 31. Dissolved Organic Carbon Concentrations and Loads from Utah Lake Tributaries.

8.4 Watershed Model Development

This section describes current watershed modeling efforts to support future nutrient loading estimates to Utah Lake.

8.4.1 University of Utah Modeling Project

As discussed above in Section 7.2, Utah Lake Nutrient Model, a multi-disciplinary research team from the University of Utah is in the process of building, calibrating and analyzing several coupled models of the Jordan River-Utah Lake watershed (Barber et al. 2015). The interactions and connections between the various models are shown in Figure 32.

The hydrology and water temperature of the non-urbanized, mountainous portion of the watershed will be simulated using the Distributed Hydrology Soil Vegetation Model (DHSVM) maintained and distributed by the University of Washington and the Pacific Northwest National Laboratory. DHSVM does not currently have the ability to simulate nutrient loading from the watershed.

The hydrology and water quality of the urbanized portion of the watershed along the Wasatch Front will be simulated using the Stormwater Management Model (SWMM) maintained and distributed by EPA. In addition, water demand, depletion, wastewater discharge and return flows of the urban systems will be simulated using GoldSim, which is maintained and distributed by the GoldSim Technology Group.

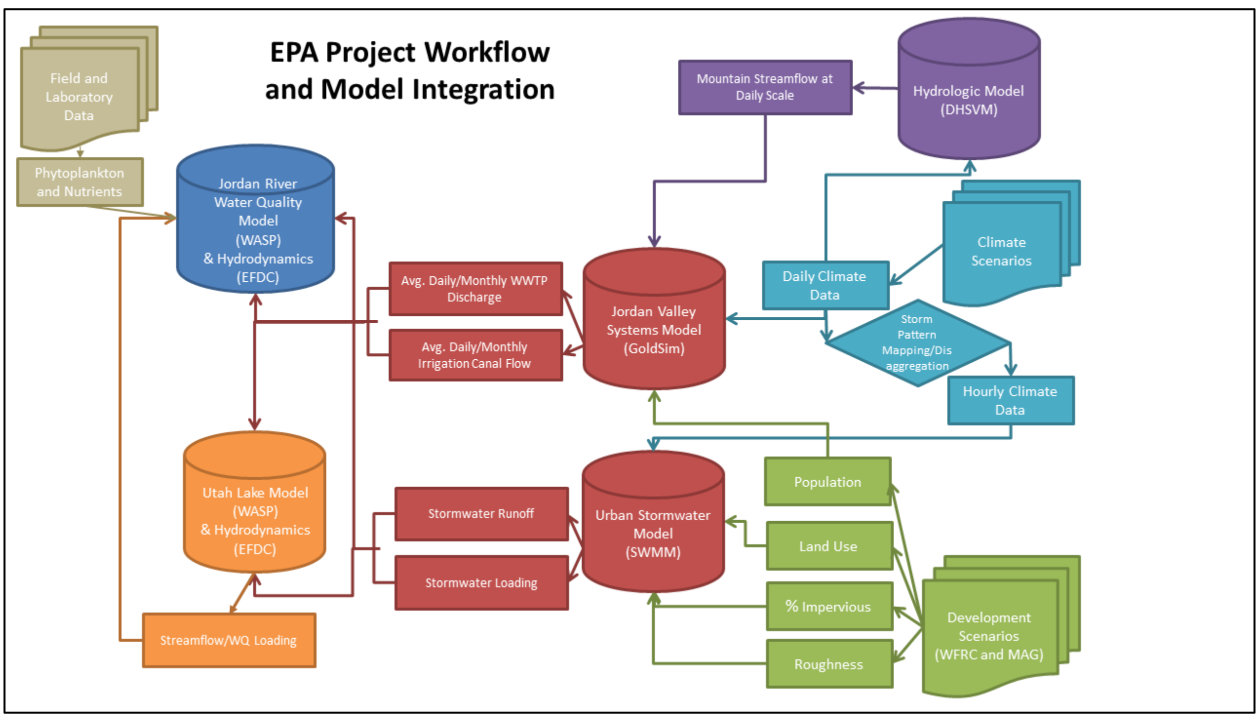


Figure 32. Utah Lake / Jordan River model integration.

8.4.2 Watershed Model Selection

Future selection of watershed models to support nutrient loading analysis and load allocations will involve stakeholders as described above in Section 3. All available options and models will be reviewed prior to selection of a watershed model. Some or all of the models being developed by the University of Utah research team, including with or without modification and recalibration, may be selected. However, a watershed model on an entirely different platform may be selected and developed, depending on the objectives and required output of the nutrient loading analysis.

9 Watershed Source Identification

Bulk nutrient loads to Utah Lake from tributaries and direct drainages are important for understanding in-lake nutrient cycling while identifying watershed nutrient sources is necessary to guide future implementation strategies. The Utah Lake Water Quality Study Steering Committee has committed to addressing source identification to determine feasible approaches for meeting in-lake goals and implementing effective watershed management approaches.

This section discusses approaches and data requirements for conducting watershed source identification. Understanding the magnitude, frequency, duration, and seasonal variability of nutrient load delivery to Utah Lake in response to a wide range of hydrologic and climatic conditions is important as well as understanding where the nutrients originated.

9.1.1 Watershed Metadata Analysis

Typical approaches for conducting a watershed source identification analysis include intensive monitoring and field inventories, characterization of water quality, and application of watershed scale models. Each approach has different data requirements and understanding them is the first step to selecting a viable approach. The selected approach should be matched to the information available through a metadata analysis that identifies limitations of the dataset, data gaps, and helps inform future monitoring programs.

The first step of a metadata analysis is to inventory datasets useful for watershed source identification. Table 21, Table 22, Table 23, and Table 24 outline the types of data typically needed to complete a watershed modeling effort or a comprehensive source assessment. The tables are divided into four general categories of information: geographic/locational information, monitoring data, land practices and activities, and other information. The necessary data are listed in the first column along with notes in the second column with further explanation and sources of each type.

Table 21. Geographic or Locational Information.

Data Type	Notes
Stream network	Digitized stream network NHD
Impaired Segments	303(d) listed reaches
Jurisdictional boundaries	Counties, towns, cities, also MS4 boundaries if available
Land use	• Local watershed land use information • USGS Multi-Resolution Land Characteristics (MRLC) • % impervious • Agriculture by type
Soils	County soil surveys STATSGO
Watershed boundaries	Digitized watershed boundaries State watershed boundaries
Topographic relief and elevation data	USGS 7.5 minute Topo, Digital Elevation Model
Water quality and biological monitoring station locations	Monitoring station locations (spatial coverages, if available, or coordinates)
Meteorological station locations	Local weather stations and locations NOAA-NCDC, EarthInfo Data
Permitted facility locations	Permitted facility discharge locations (spatial coverages, if available, or coordinates) specifically, all facilities permitted to discharge nutrients in the drainage area
Municipal sewer service area boundaries	Locations, if known
Onsite Wastewater Treatment Systems	Locations, if known
Municipal Water intakes/withdrawals	Locations and quantities if known
Storm water infrastructure	Location of drains, inlets, outlets, BMPs, etc.
Points of Diversion	Locations of diversions for agriculture and quantities of water permitted or actually diverted
Irrigation infrastructure	Locations of the irrigation network (canals, ditches, other conveyances)
Irrigated lands	Location and type of irrigation (sprinkler, flood, etc.)
Tile Drains	Location of the tile drain network
Dams	Location of all dams/reservoirs in the watershed

Table 22. Monitoring Data.

Data Type	Notes
Flow data (natural streams/rivers)	Continuous and/or instantaneous flow data collected by: • USGS • DEQ • Others
Flow data (agricultural, industrial, municipal uses)	Continuous and/or instantaneous flow data from water diversions, withdrawals, returns, tile drains, etc.
Flow data (transbasin diversions)	Is any water diverted from the Utah Lake watershed to another watershed, or is any water diverted into the Utah Lake watershed from another watershed?
Lake elevation	Lake level monitoring data
Meteorological data	Local weather data
Water quality data (including ambient, lake monitoring, sediment, etc.)	Historical and current water quality monitoring data for the lake and watershed tributaries (e.g., nutrients, sediment, temperature, DO., etc.) collected by: • DEQ • Others
UPDES Permitted facilities DMR data	Facility discharge data

Table 23. Land Practices and Activities.

Data Type	Notes
Agricultural Activities	If relevant, BMPs, cropping practices, grazing allotments and management, irrigation management practices - withdrawals and return flows etc
Turf management	Golf course practices
Urban Activities	Stormwater runoff control practices, outfall locations, monitoring data, etc.
On-site Wastewater	Septic System locations, Failure rates
Water Rights	How is the diversion of water from Utah Lake and its tributaries regulated?
Wildlife	Species, prevalence, location

Table 24. Other Information.

Data Type	Notes
Other water quality/hydrology reports	Previous reports/studies that may have compiled and summarized water quality and/or hydrology data
List of ongoing lake and watershed studies	Who is currently studying the lake/watershed and what are they doing?
Citizen complaints, other reports	

9.2 Utah Lake Source Characterization

The data types presented in Table 21, Table 22, Table 23, and Table 24 were identified to help characterize the potential nutrient sources in the watershed. For Utah Lake these include background, or natural, sources that are not influenced by land use and water management activities including ground water, springs, natural erosion, and natural atmospheric deposition. Anthropogenic, or human caused, sources of nutrients are introduced by land and water management activities and include stormwater runoff, point source discharges, agricultural land management, streambank and land erosion, and atmospheric deposition from human sources.

9.2.1 Hydrologic Influence on Loading

Hydrologic conditions in a watershed can significantly affect timing, magnitude, and duration of nutrient loads delivered to Utah Lake from the surrounding watershed. Precipitation driven sources like upland and streambank erosion are examples. During high flow events, erosion is more likely and therefore more likely to transport loading to the lake. During low flow and base flow conditions nutrient sources will be conveyed differently than during high flows.

The first step in determining hydrologic influences on source delivery is to evaluate the hydrograph for the location of interest and determine if water quality sampling is representative of all flow conditions. Figure 33 and Figure 34 show the hydrographs of daily average flow sampled at respective USGS gages for Hobble Creek and Provo River monitoring stations. The Hobble Creek location shows good temporal distribution for the active sampling period of the USGS gage (2008 to Current). The figure also shows that water quality samples were collected at high flow events, low flow events, and mid-range flow conditions (Figure 33). A similar observation can be made at the Provo River location, however, water quality monitoring began in 2016 and water chemistry data is not available for a period sufficient to represent all flow regimes (Figure 34).

The Provo River and Hobble Creek sites are the only two sampling locations representing lake inflow conditions with continuous USGS flow measurements and a similar comparison cannot be made at other stations. DWQ installed continuous pressure transducer monitoring stations at all inflow tributaries to begin developing a dataset for this purpose.

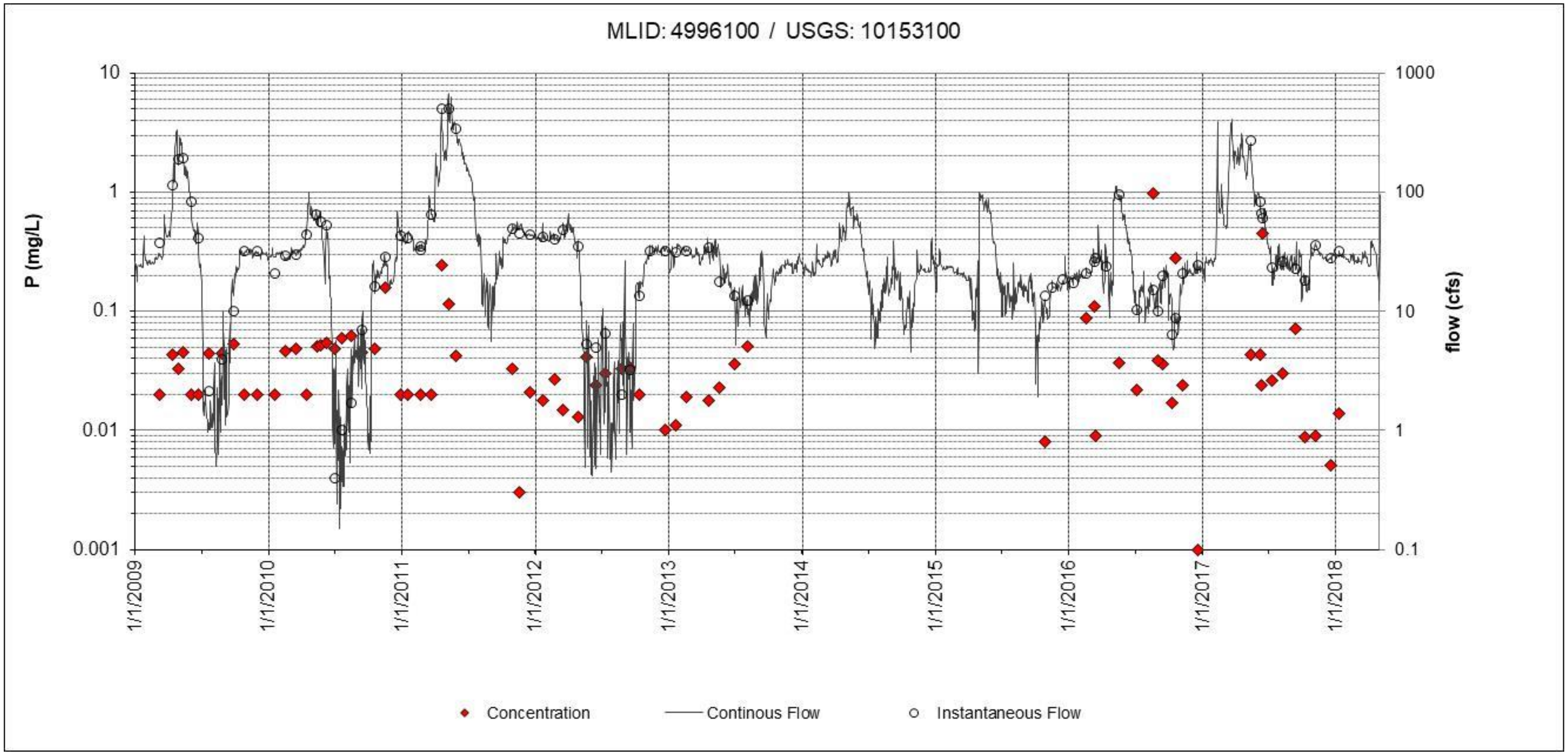


Figure 33. Hobble Creek hydrograph showing paired instantaneous flow and water quality samples.

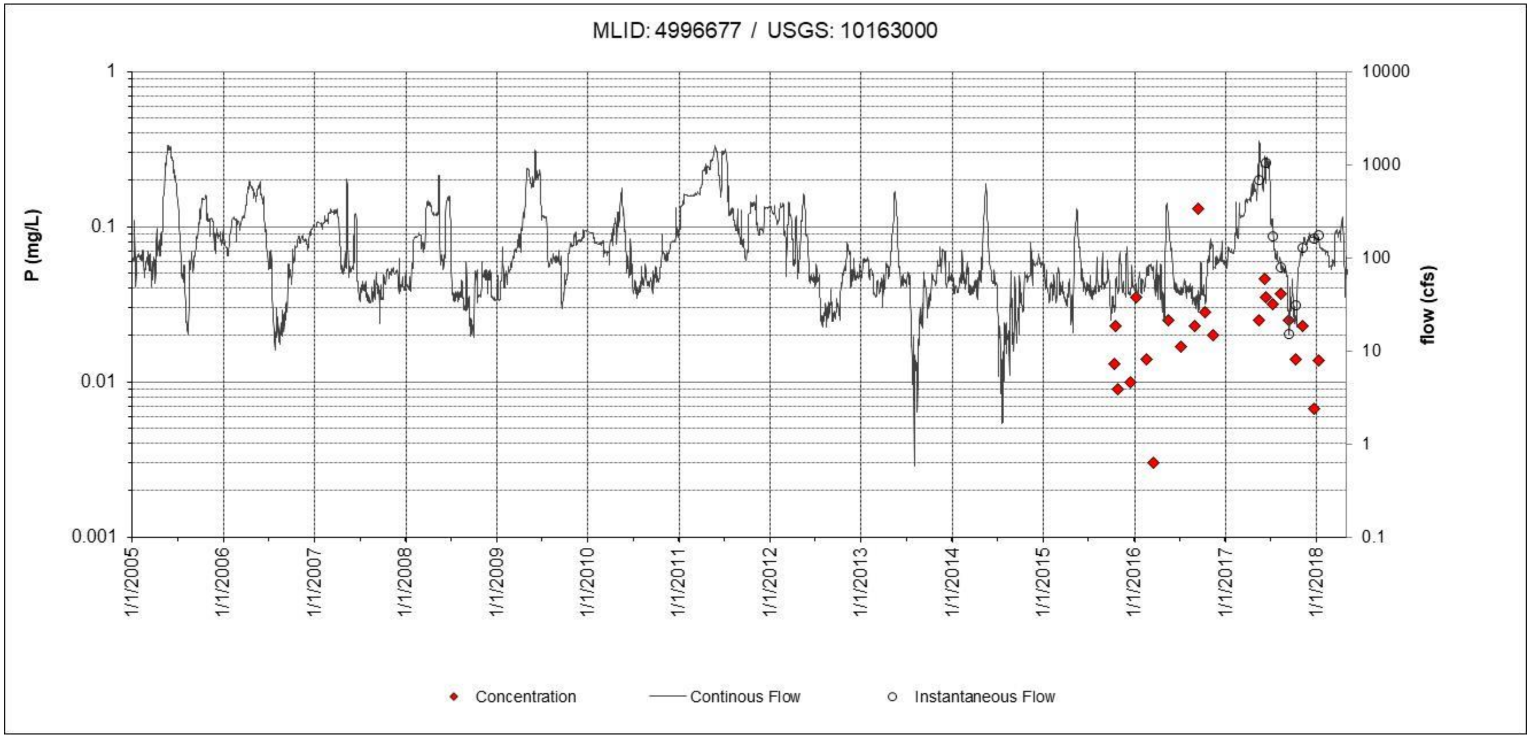


Figure 34. Comparison of water quality samples and flows over a range of temporal and hydrologic conditions for Provo River.

9.2.1.1 Characterize magnitude/duration/timing

Further investigation of flow conditions frequency allows empirical evaluation of water quality samples and the flow conditions they represent. A flow frequency curve is a distribution of flow values ranked from highest to lowest and presented as a percentage of the entire data record flow exceeds an individual value. Figure 35 shows the flow frequency curve for USGS daily flow at Hobble Creek above I-15. The figure shows that flow is greater than 10 cfs about 85 percent of the time. In contrast, flow exceeds 100 cfs about 7 percent of the time. Instantaneous flow values collected with paired water quality samples are also plotted in Figure 36.

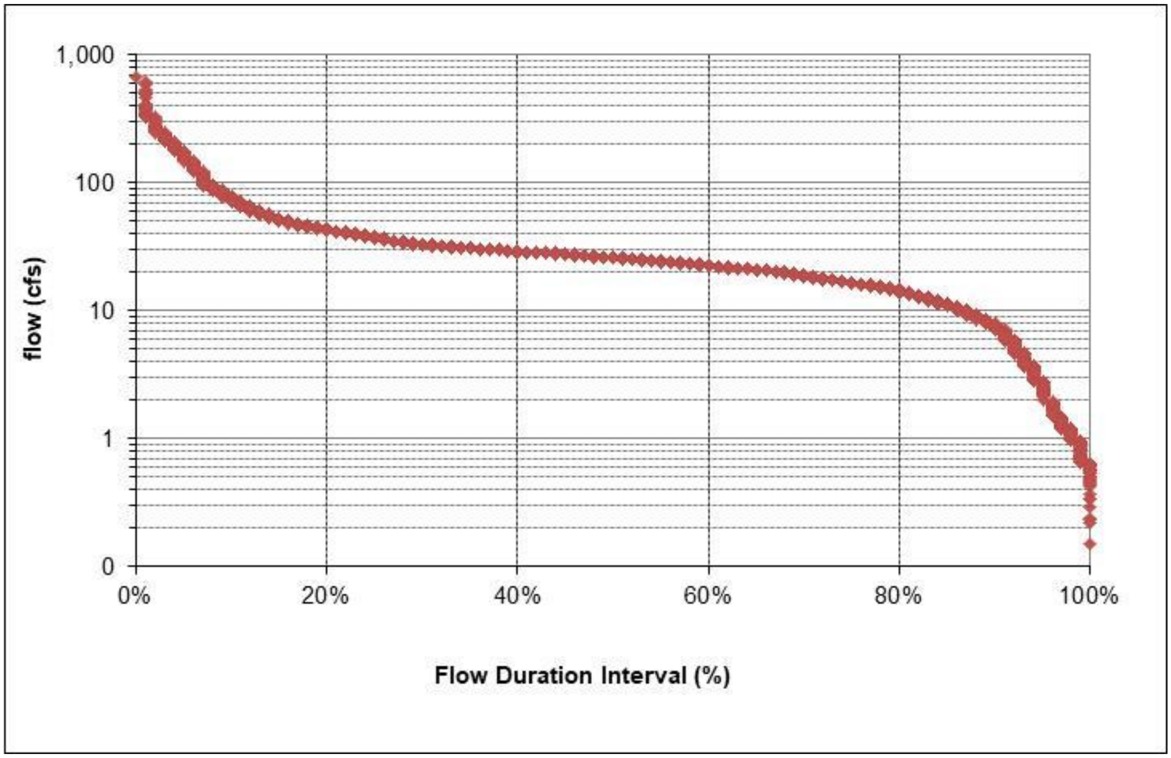


Figure 35. Flow Frequency Curve for Hobble Creek above I-15.

Flow exceedance curves can be further modified to represent loading conditions. For the purpose of TP, USGS flow was multiplied by DWQ's stream nutrient indicator value to develop a load capacity curve. Plotting observed TP load over this curve shows that water quality samples are well distributed for most flow regimes (Figure 36). However, sample frequency is not sufficient to accurately characterize loading within each flow regime. For example, only 7 samples represent flows between 20% and 60%. To develop a significant relationship of loading and flow, 30 or more samples are recommended for each 10 to 20% flow interval. Additionally, continuous flow data does not exist to do these analyses at all tributary locations. It is recommended to continue developing continuous flow datasets to help accurately target water quality sampling efforts.

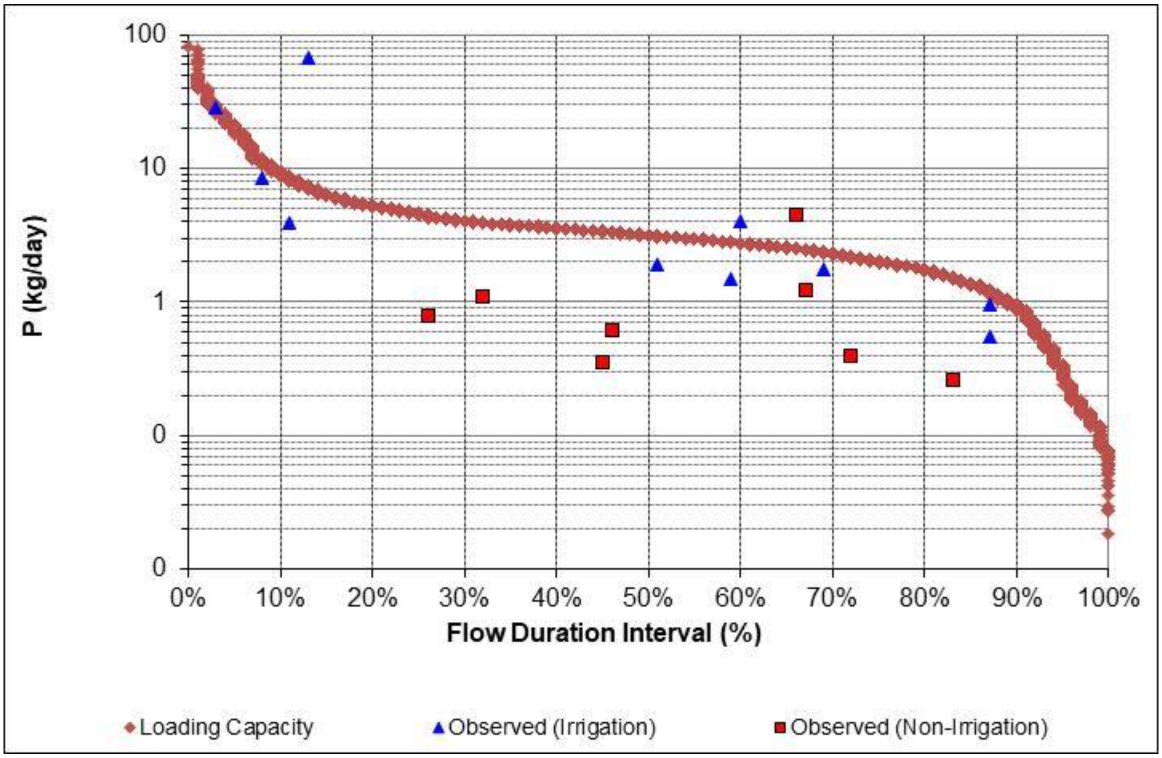


Figure 36. Load Duration Curve for Hobble Creek above I-15.

9.2.2 Stormwater

Nutrient loading from stormwater runoff is not well characterized in the Utah Lake watershed and is suspected to contribute significantly to the lake's nutrient budget. However, there is no known or readily available information to characterize flow and water quality associated with this source in Utah County.

9.2.2.1 Utah Lake Watershed Land Uses

Land use characteristics for the Utah Lake watershed from the Multi-Resolution Land Characterization dataset (MRLC) were used to identify urban and residential landscapes contributing to stormwater runoff. Table 25 and Figure 37 show the land use distribution for all types within the watershed. Note, that for the purpose of this analysis the watershed was delineated to exclude the Provo River above Deer Creek Reservoir and all trans-basin diversions from the Weber River and Strawberry River watersheds. Land uses that have potential to contribute stormwater include developed high intensity, developed low intensity, developed medium intensity, and developed open space, which make up approximately 7% of the total watershed area. Figure 37 shows these land uses are located predominately along the Wasatch Front, adjacent to Utah Lake.

Table 25. Land Use Types in the Utah Lake Watershed.

Land Use Type	Area (acres)	Percent Total Area
Barren Land (Rock/Sand/Clay)	11,302	0.81%
Cultivated Crops	49,716	3.56%
Developed High Intensity	9,079	0.65%
Developed, Low Intensity	33,981	2.44%
Developed, Medium Intensity	27,723	1.99%
Developed, Open Space	29,138	2.09%
Emergent Herbaceous Wetlands	12,699	0.91%
Evergreen Forest	234,412	16.81%
Forest	419,488	30.08%
Grassland/Herbaceous	49,427	3.54%
Mixed Forest	3,490	0.25%
Open Water	94,031	6.74%
Pasture/Hay	90,933	6.52%
Shrub/Scrub	324,601	23.27%
Woody Wetlands	4,741	0.34%
Grand Total	1,394,761	**100.00%**

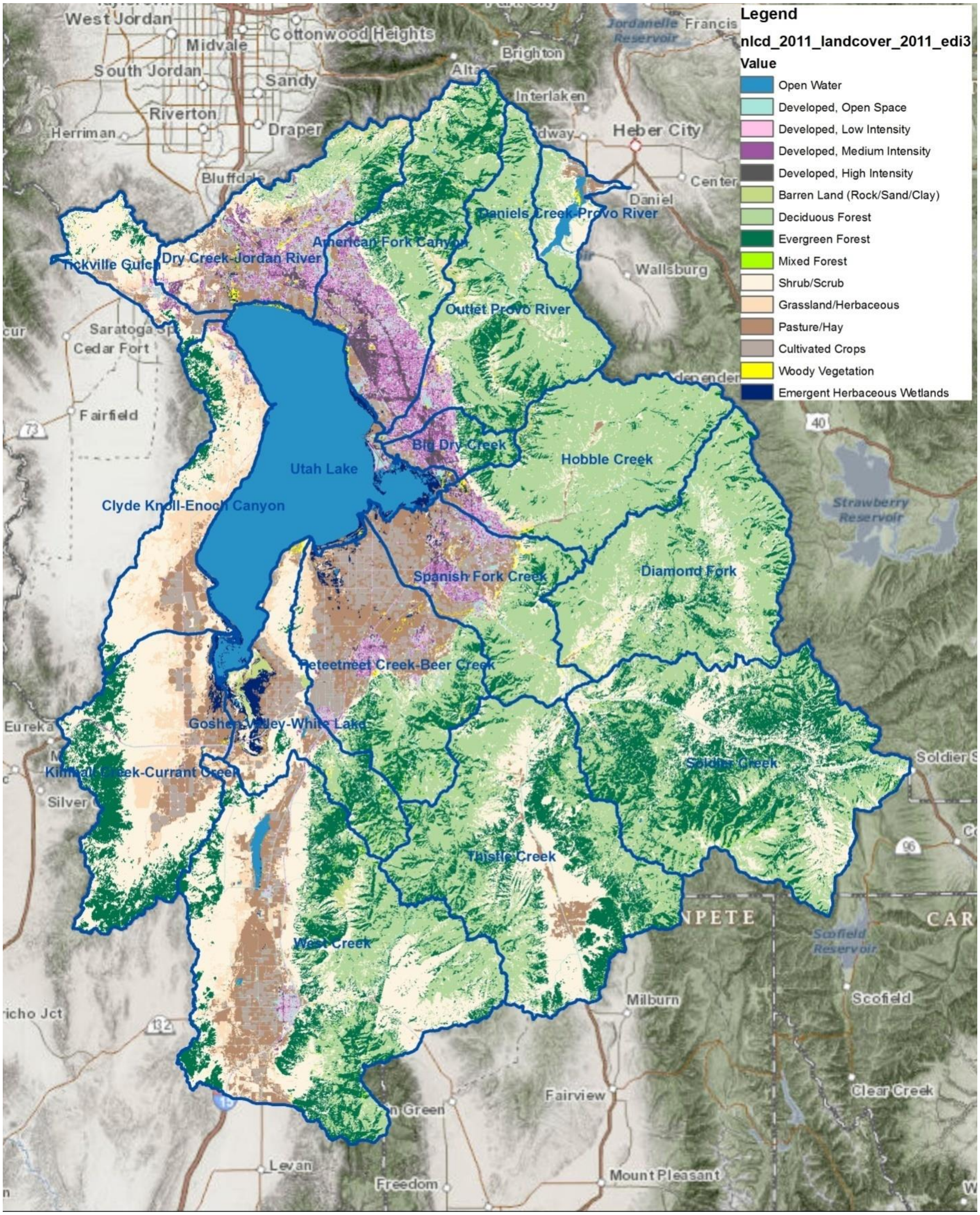


Figure 37. Land Use Distribution in the Utah Lake Watershed.

The following section summarizes four methodologies used to calculate the estimated annual Total Phosphorus (TP) load to Utah Lake attributed to stormwater runoff from developed areas. As there is no known stormwater monitoring data available for the Utah Lake watershed, loading factors and stormwater monitoring data from other watersheds in northern Utah were used together with Utah Lake watershed land use and precipitation data. The methodologies and data sources are described below.

9.2.2.2 Method 1: East Fork Canyon/Cutler TMDL Loading Coefficients

Previous TMDL studies in the East Canyon Creek and Cutler Reservoir watersheds completed by DWQ estimated stormwater contributions using a land use coefficient based approach. The East Canyon Reservoir and East Canyon Creek Total Maximum Daily Load (SWCA, May 2010) and Middle Bear River and Cutler Reservoir Total Maximum Daily Load studies (SWCA, February 2010) developed TP loading coefficients for land uses in the study watersheds. The Little Bear River Subwatershed-2 drainage load coefficients were derived from a model developed by Utah State University. BIO-WEST performed a detailed analysis of the Summit County portion of the Upper East Canyon watershed in 2000 and 2007 and estimated loads based on monitoring data and regression analyses. The Little Bear River and Upper East Canyon Load Coefficients are summarized in Table 26.

Table 26. East Canyon and Little Bear River Watershed TP Loading Coefficients.

East Canyon Watershed		Little Bear River Drainage	
Land Uses	**Normalized P Load (kg/ha/yr)**	**Land Uses**	**Total P load (kg/ha/yr)**
Background	0	Water	-
Forested/meadow	0	Residential	0.77
Residential	0.1	Commercial/industrial/transportation	0.81
Ski areas	0.2	Barren	0.35
Ag/grazing	0.1	Forest	0.05
Golf courses	0.3	Rangeland	0.05
Active construction	0.5	Irrigated Row Crops/small grains	1.46
High use recreation	0.1	Irrigated Pasture/Fallow/Orchard	1.1
Commercial urban	0.3	Non irrigated Agriculture	1.59
Open water	-	Wetlands	0.04

The East Canyon and Little Bear River Drainage TP Loading Coefficients were applied to developed land uses surrounding Utah Lake to calculate a TP annual load. The estimated TP load from the developed land area in the Utah Lake Watershed is 6 tons/year based on the East Canyon loading coefficients and 27 tons/year based on the Little Bear River (Cutler TMDL) loading coefficients as shown in Table 27.

Table 27. Utah Lake Developed Areas Total P Load Based on East Canyon and Little Bear River Loading Coefficients.

Utah Lake Land Uses	Area (acres)	East Canyon P Load (kg/ha/yr)	Little Bear River P Load (kg/ha/yr)	East Canyon P Load (kg/yr)	East Canyon P Load (metric tons/yr)	Cutler Reservoir P Load (kg/yr)	Cutler Reservoir P Load (metric tons/yr)
Developed High Intensity	3,674	0.1	0.35	1179.16	1.18	4,127.08	4.13
Developed, Low Intensity	13,752	0.1	0.77	1375.16	1.38	10,588.76	10.59
Developed, Medium Intensity	11,219	0.2	0.79	2243.85	2.24	8,863.24	8.86
Developed, Open Space	11,792	0.3	0.81	1102.25	1.10	2,976.07	2.98
Total	**40,437**				**5.9**		**26.6**

9.2.2.3 *Method 2: Average Annual Runoff (Curve Number Method) and Salt Lake County Monitoring Data*

Since stormwater monitoring data for Utah County is not available, the median TP concentration from the Salt Lake County Monitoring Dataset was multiplied by the average annual runoff for Utah Lake watershed developed land uses to estimate a TP load from stormwater to Utah Lake. Salt Lake County has collected and analyzed stormwater samples for TP from 14 locations from 1992 through 2016. The median value of this data is 0.375 mg/L.

Runoff from developed areas in the Utah Lake watershed was estimated using the rainfall-runoff curve number method developed by the USDA and described in the National Engineering Handbook (NRCS, 2009). Curve numbers are unitless representations of the portion of runoff expected for an area based on unique soil/land-use combinations. Curve numbers range from a low of 1 to a high of 100. Higher curve numbers indicate the potential for more runoff during a storm event and are influenced by slow draining soils and impervious cover.

Soil types in the watershed were classified by their hydrologic class (A, B, C, or D) as defined in the NRCS Soil Survey Geographic (SSURGO) database. Class D soils are general poorly drained and shallow whereas Class A soils are generally well-drained and deep. The percentage of each soil hydrologic group for the Utah Lake watershed land uses was determined using GIS, and an area weighted curve number was assigned for each land use.

Historical precipitation data recorded at both the Orem Water Treatment Plant and Provo BYU stations was analyzed to determine average annual rainfall. The average of these two stations is approximately 15 inches per year. Using the rainfall-runoff curve number approach, the area of the developed land uses in Utah County and a median TP value of 0.375 mg/L, the TP load was estimated at 18 tons/year (Table 30).

Table 28. Utah Lake Developed Area as Total P Load Based On Salt Lake County TP Concentrations and Average Annual Runoff.

Utah Lake Land Uses	Area (acres)	Curve Number	Runoff, Q (in/yr)	Runoff Volume (cubic feet/yr)	Runoff Volume (liters/yr)	Load (metric tons/yr)
Developed High Intensity	3,674.2	95	14.36	1.92E+08	5.42E+09	2.03
Developed, Low Intensity	13,751.6	75	11.6	5.79E+08	1.64E+10	6.15
Developed, Medium Intensity	11,219.3	73	11.3	4.60E+08	1.30E+10	4.89
Developed, Open Space	11,791.6	74	11.45	4.90E+08	1.39E+10	5.21
Total	**40,436.7**		**48.7**	**1.72E+09**	**4.87E+10**	**18.3**
Avg Annual Rainfall Orem/Provo (inches), P=14.98						

9.2.2.4 *Method 3: Jordan River TMDL Stormwater Load*

The projected TP load to the Jordan River from direct stormwater outfalls was calculated to be 34 tons/year in the Jordan River TMDL (Cirrus Ecological Solutions, LC/Stantec Consulting Inc., June 2010). The Jordan River TMDL load calculation was based on flows from stormwater catchments, a weighted average runoff coefficient that accounts for 10 different land cover types throughout all of Salt Lake County and existing valley wide average event mean concentrations from water quality monitoring data collected since 1992.

The area of the Salt Lake County developed area was obtained from GIS data provided by Salt Lake County Flood Control (255,142 acres). The Jordan River TMDL TP load of 34 tons /year was scaled to the developed area of Utah County (99,919 acres) to calculate an estimated TP load to Utah Lake of 13 tons per/year from stormwater.

9.2.2.5 *Method 4: Simple Method to Calculate Pollutant Loads using Average Annual Rainfall and Salt Lake County Monitoring Data*

The Simple Method (Schueler, 1987) estimates stormwater runoff pollutant loads for urban areas. The technique requires subwatershed drainage area and impervious cover, stormwater runoff pollutant concentration, and annual precipitation. The Simple Method is most appropriate for assessing and comparing relative stormwater pollutants loads for different land use and management scenarios and may not be applicable for watersheds greater than one square mile (640 acres). Due to the modest information required for this method, the TP load was calculated to compare with the other methods described above.

Similar to Method 2, precipitation data from Orem and Provo were analyzed to determine the average annual rainfall of 15 inches per year and the Salt Lake County monitoring data median TP of 0.375 mg/L was used for the calculation. The total phosphorous load based on the Simple Method is 9 tons/year. The calculations are summarized in Table 29.

Table 29. Simple Method to Calculate TP Load to Utah Lake from Stormwater

Utah Lake Land Uses	Area (acres)	Impervious Fraction	Annual Runoff, R (in)	Runoff Coefficient	Load (metric tons/yr)
Developed High Intensity	3,674	0.9	11.59	0.86	1.64
Developed, Low Intensity	13,752	0.3	4.31	0.32	2.28
Developed, Medium Intensity	11,219	0.6	7.95	0.59	3.43
Developed, Open Space	11,792	0.2	3.10	0.23	1.41
Total	**40,437**				**8.76**
Avg Annual Rainfall Orem/Provo (inches), P=14.98					

9.2.2.6 *Summary*

The four methods used to estimate TP stormwater load from the developed portion of Utah Lake are summarized in Table 6. The calculated load is 6 - 27 tons per year. The estimated TP contribution from the POTWs to Utah Lake is of 270 tons/year (Psomas/SWCA, 2007). Based on these estimates the stormwater contribution is 2-10% of the POTWs contribution.

Table 30. Summary of Total Phosphorous Load Estimates to Utah Lake from Four Stormwater Calculation Methods.

	Calculation Method	Utah Lake TP Load (tons/yr)
1	East Fork Canyon TMDL TP Load Coefficients	6
	Cutler TMDL TP Load Coefficients	27
2	Runoff/SL Co monitoring TP concentration	18
3	Jordan River TMDL Stormwater Load	13
4	Simple Method to Calculate Urban Stormwater Loads	9

The methods used to estimate TP to Utah Lake from stormwater utilize Utah Lake watershed land use data and historical precipitation data, and TP concentrations and loading coefficients from elsewhere in Northern Utah due to the absence of such data in the Utah Lake watershed. These methods consider stormwater runoff from only the developed land uses within the watershed (Low, Medium and High Intensity Developed and Developed Open Space). In addition, these methods estimate TP load generated only during storm events. It does not consider pollutants associated with base flow volume nor do the methods consider stormwater routing in this evaluation. More sophisticated modeling is needed to accurately estimate the TP pollutant load from developed land uses in the watershed.

9.2.3 UPDES Discharge Facilities

Several industrial and municipal dischargers are located in Utah County and discharge to Utah Lake tributaries (Table 31 and Figure 38). Resulting from the implementation of the Technology Based Phosphorus Effluent Limit rule in 2014, municipal discharge facilities are required to monitor for nutrient parameters. This data is submitted regularly to DWQ and is maintained in the EPA ICIS database. This data is available to the ULWQS for further analysis. A summary of daily discharge for these facilities is presented in Figure 39. Paired concentrations and loads for reported nutrient parameters are shown in Figure 40 through Figure 44. Other nutrient related parameters included in this dataset are ammonia, total nitrogen, nitrates, and ortho-phosphate.

Table 31. UPDES Permits.

UPDES_ID	Permit Type	Permit Name	Receiving Waters
UT0000361	Industrial	ANDERSON GENEVA, LLC & ICE	UTAH LAKE
UT0000612	Industrial	MCWANE DUCTILE-UTAH	IRONTON CANAL
UT0020109	Municipal	SPANISH FORK CITY	DRY CREEK
UT0020249	Municipal	SALEM CITY	BEER CREEK THEN UTAH LAKE
UT0020427	Municipal	PAYSON CITY	BEER CREEK/UTAH LAKE
UT0020834	Municipal	SPRINGVILLE CITY	SPRING CREEK
UT0020915	Municipal	OREM CITY	POWELL SLOUGH
UT0021717	Municipal	PROVO CITY	MILLRACE CREEK
UT0023639	Municipal	TIMPANOGOS SPECIAL SERVICE DIS	UTAH LAKE
UT0024422	Industrial	FLOWSERVE,INC./VALTEK	REFLECTIVE POND TO SPRING CREEK
UT0025097	Industrial	NRP Jones, LLC	Nephi City Irrigation Ditch
UT0025283	Industrial	ENSIGN-BICKFORD - HOBBLE CREEK	HOBBLE CREEK and Spanish Fork River
UT0025321	Municipal	SARATOGA SPRINGS	UTAH LAKE WETLANDS
UT0025518	Industrial	PAYSON POWER PROJECT	BEER CREEK AND THEN BENJAMIN SLOUGH
UT0025623	Industrial	PacifiCorp Energy	LINDON HOLLOW CREEK INTO UTAH LAKE
UT0025950	Municipal	Mona Wastewater Treatment Plant	Mona Reservoir
UT0026000	Municipal	Santaquin Water Reclamation Facility	Cities Winter Storage Ponds

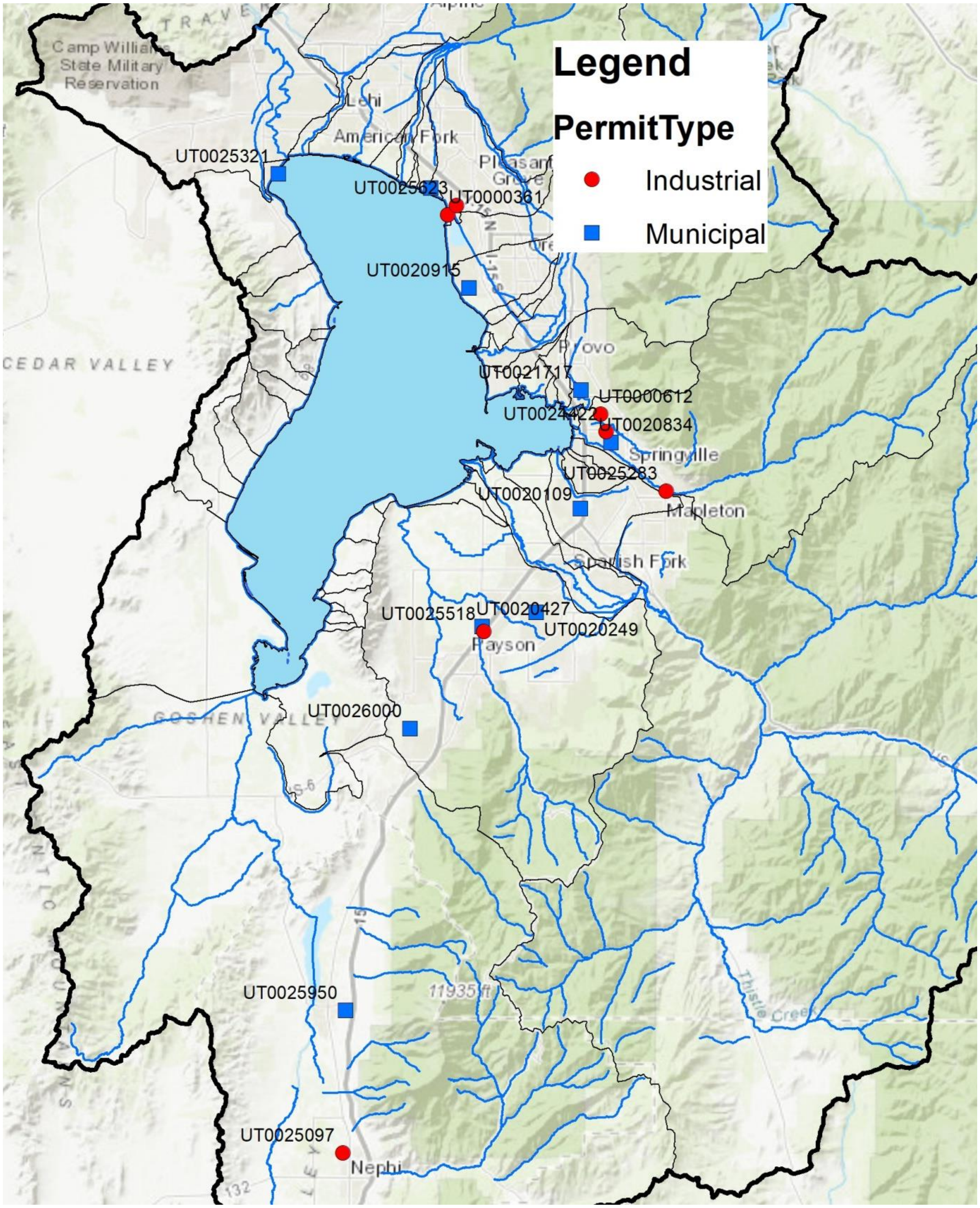


Figure 38. UPDES Discharge Locations.

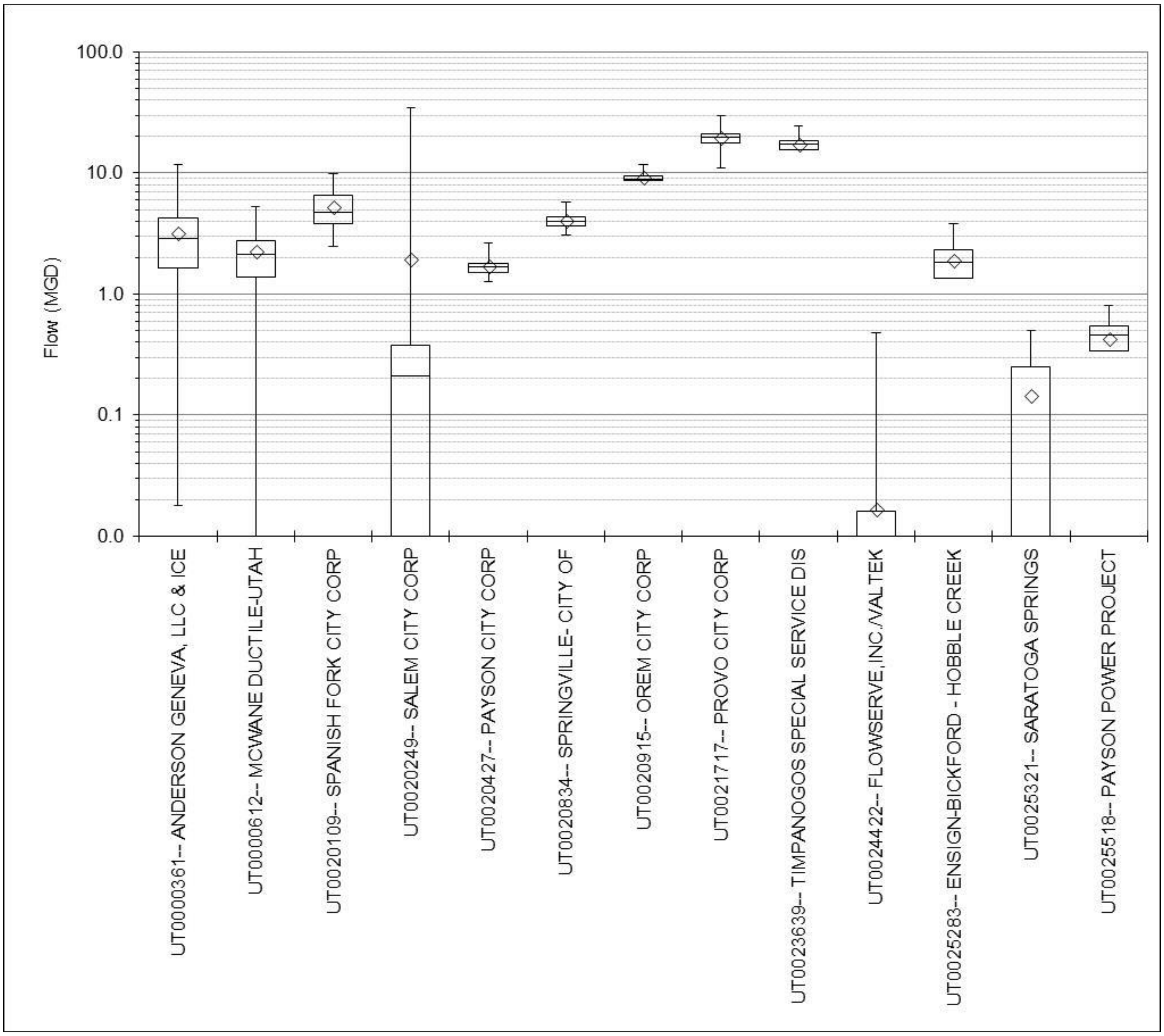
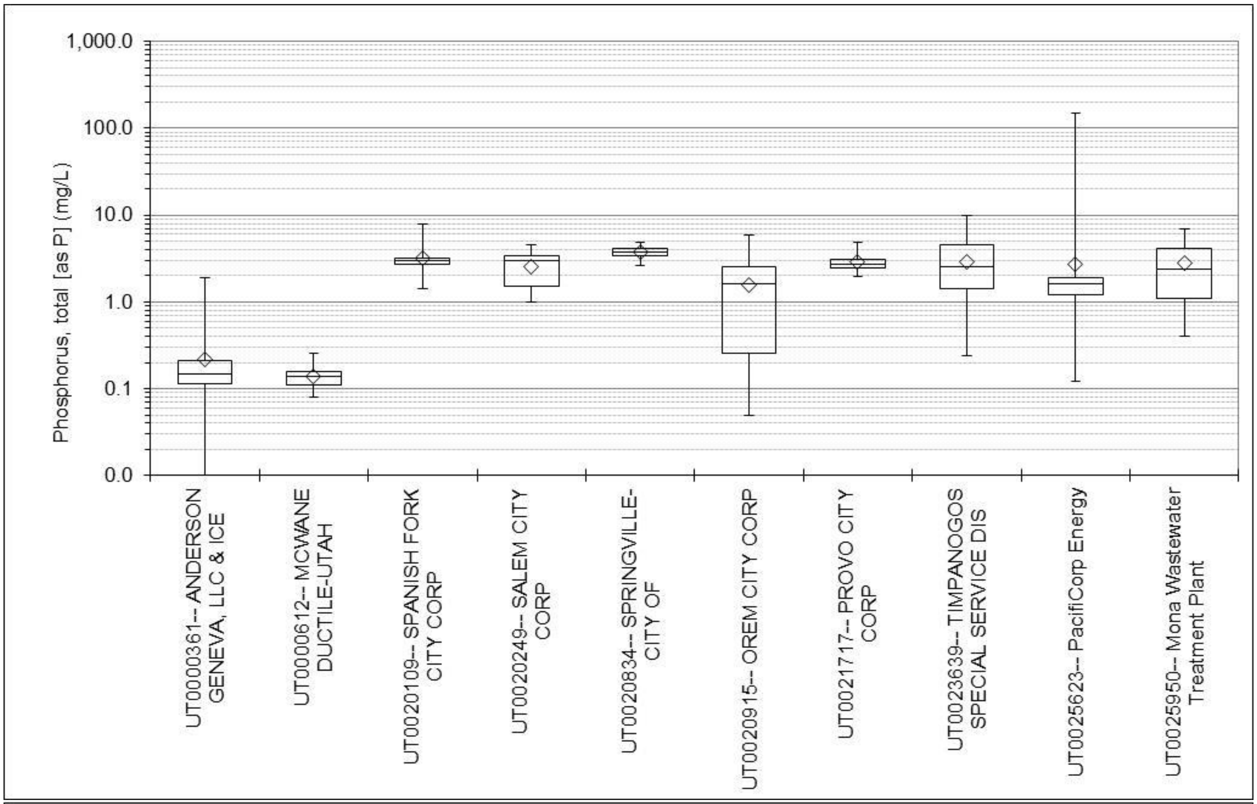


Figure 39. UPDES Facility Daily Discharge Rates.



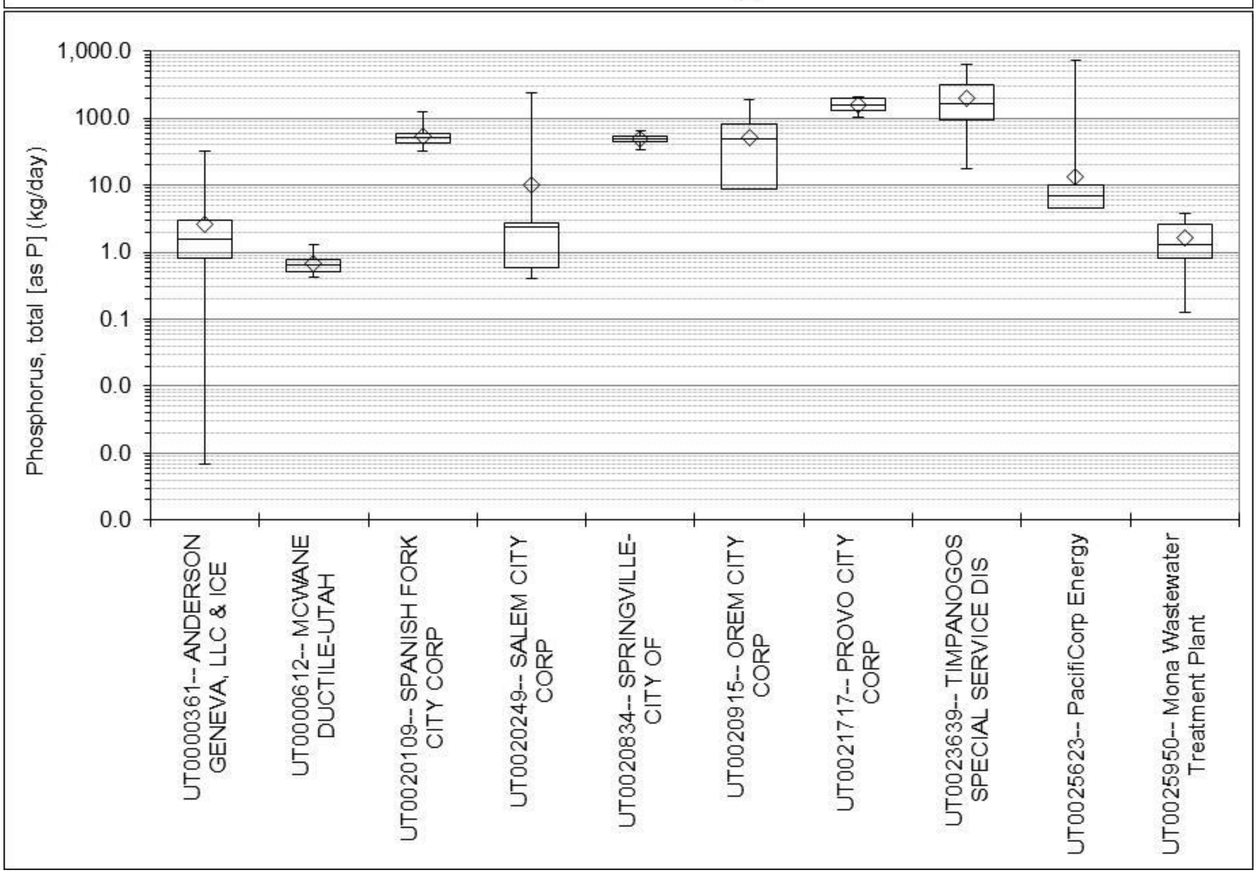


Figure 40. UPDES Facility Total Phosphorus Concentrations and Daily Loads.

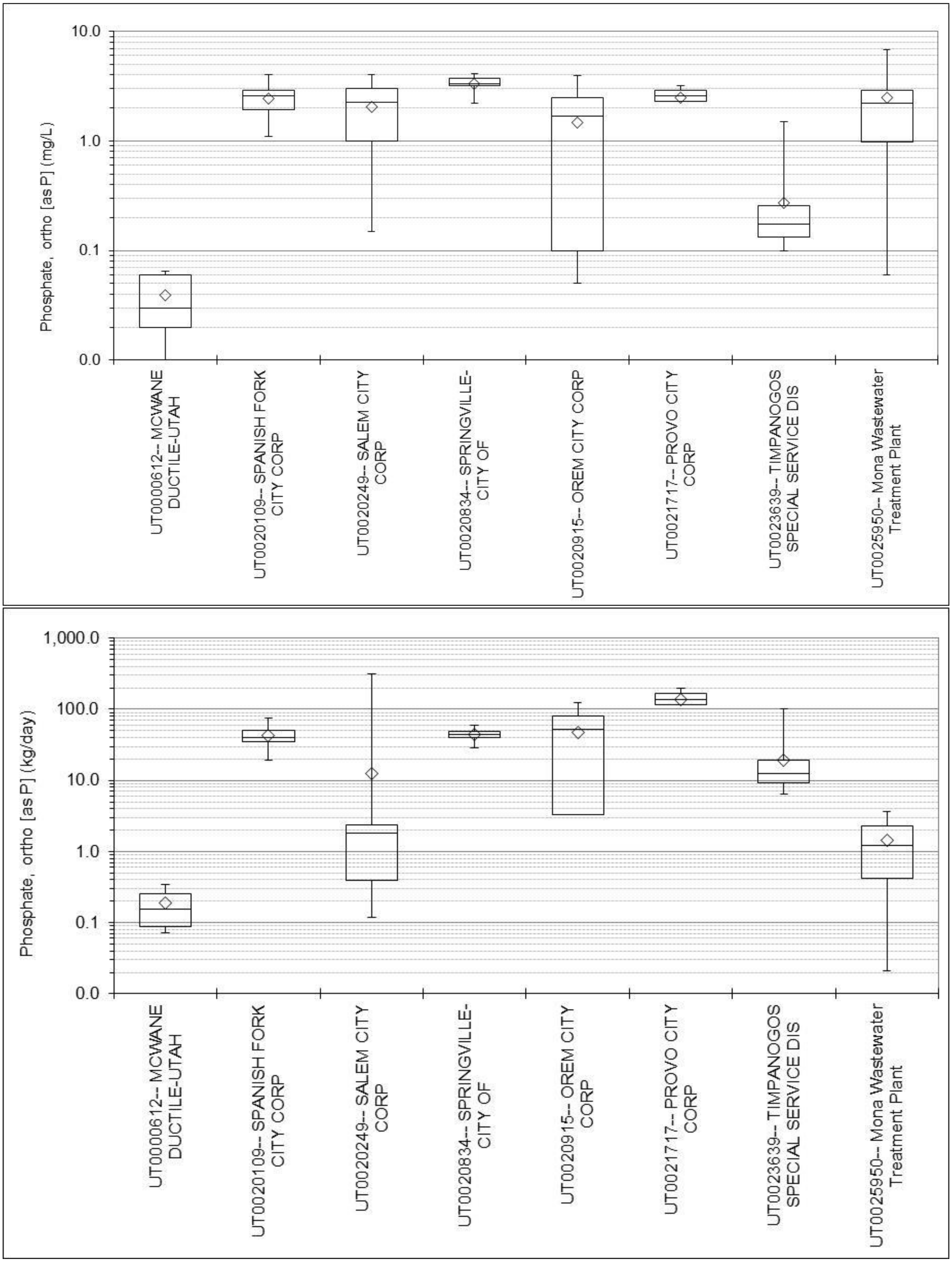


Figure 41. UPDES Facility Ortho Phosphate Concentrations and Daily Loads.

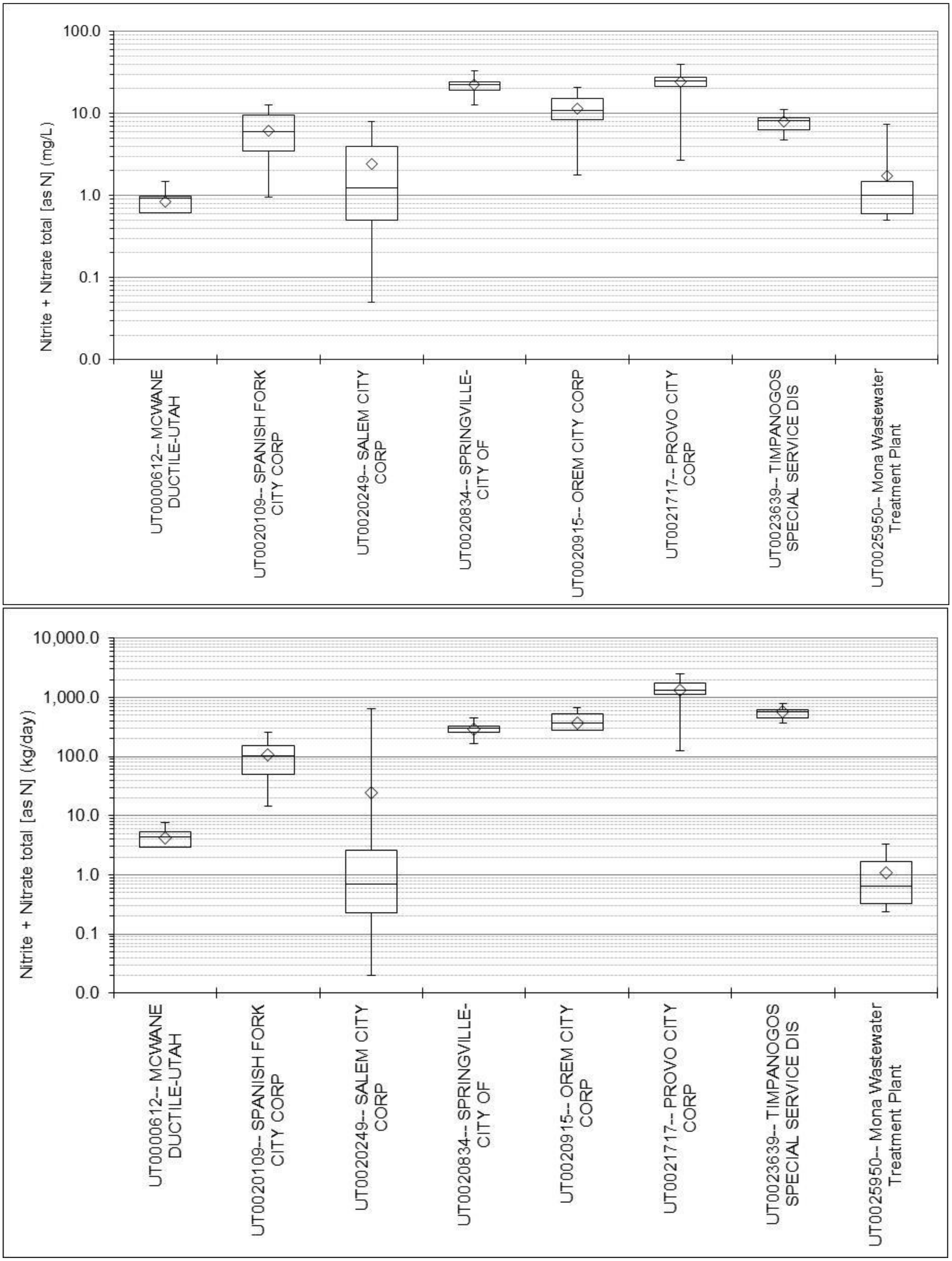


Figure 42. UPDES Facility Nitrate Plus Nitrite Concentrations and Daily Loads.

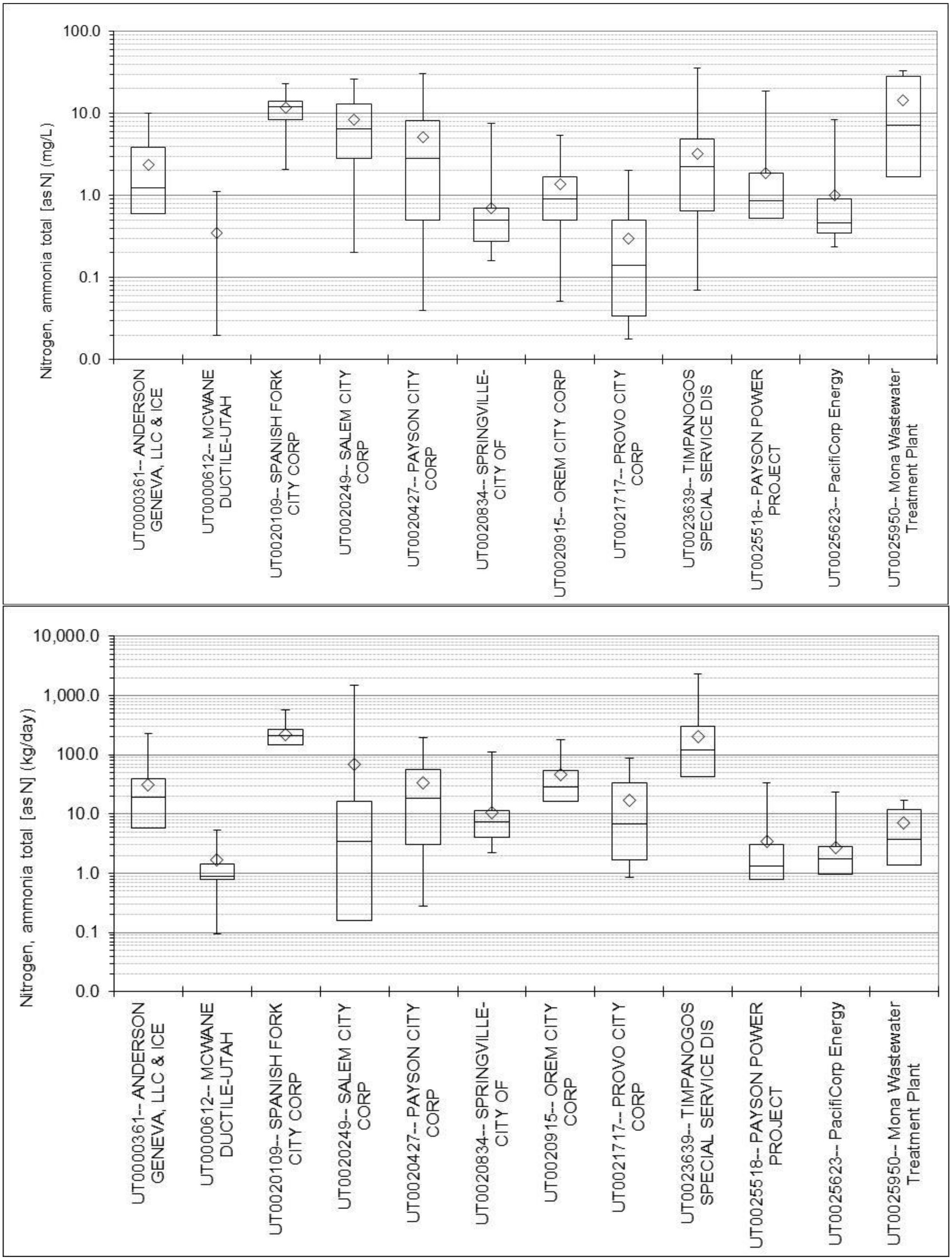


Figure 43. UPDES Facility Ammonia Concentrations and Daily Loads.

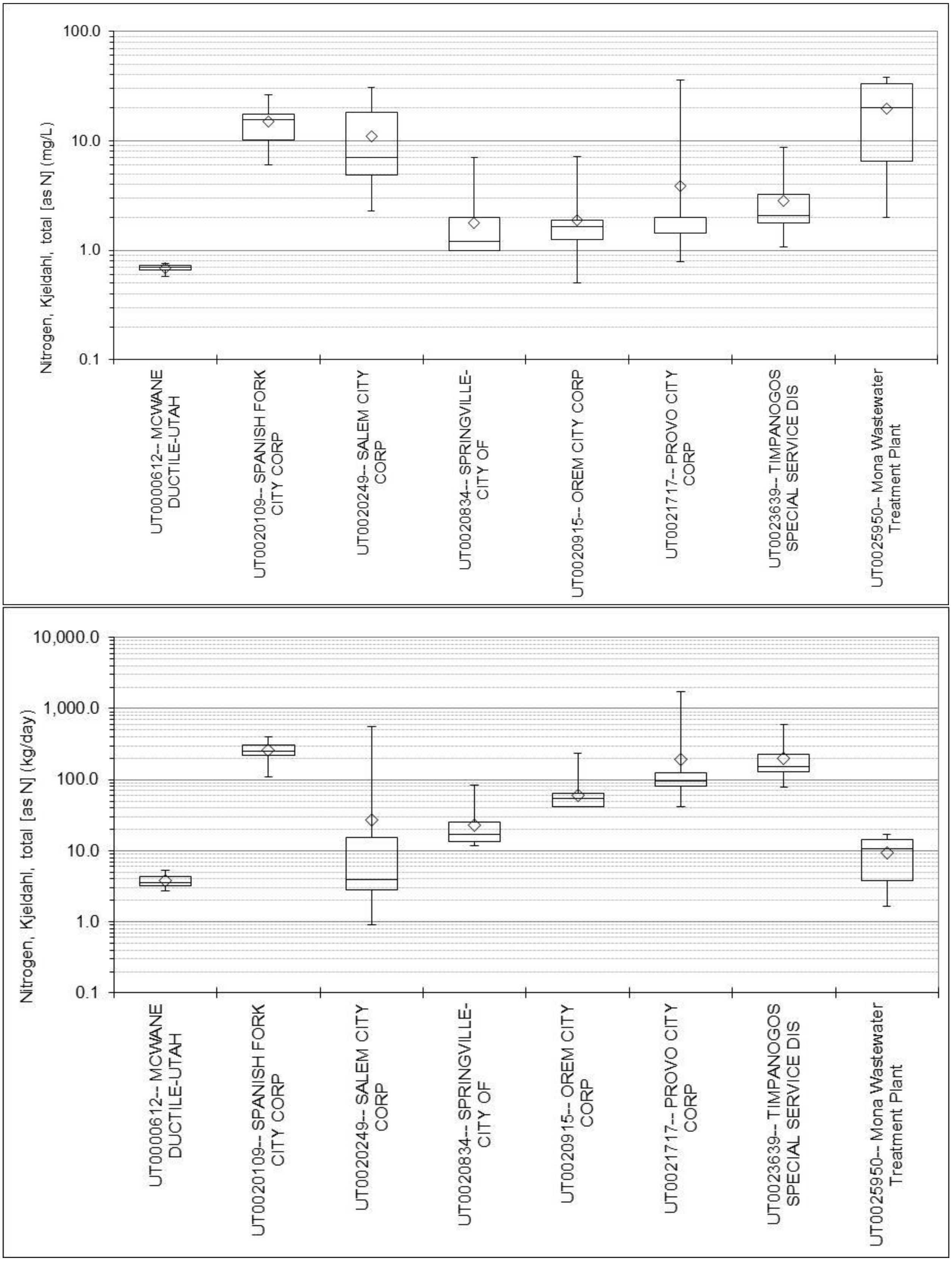


Figure 44. UPDES Facility TKN Concentrations and Daily Loads.

10 Recommendations

Several recommendations for future data collection, analysis, and model development are suggested for Phase 2 and Phase 3 of the ULWQS. These are presented below with reference to their respective work element.

10.1 Data Management and Compilation

The ULWQS Phase 1 effort was effective at identifying available water quality and ecosystem data sets relevant to nutrient dynamics in the lake. Ongoing research and data collection by BYU, UVU, USU, U of U, DWQ, and others continue to develop this dataset. However, additional effort is needed to coordinate ongoing monitoring and data compilation. A number of outstanding datasets exist that will be useful to the project including additional water quality data for inflow and open water sites (Table 10).

- Improve coordination of data collection and sharing efforts
- Inflow identification and monitoring
- Continuous flow

10.2 Water Quality Assessment and Analysis

The Water Quality Assessment and Analysis section uses the DWQ 2016 Integrated Report as the baseline dataset and assesses additional data collected during 2015 and 2016. This analysis attempts to compare available data against water quality standards to determine if designated uses are being supported. Two significant data gaps are identified in the section including insufficient data and methods to assess support of downstream uses of Utah Lake water and protection of early life stages (ELS) for juvenile fish and their food web. Limited information is known about downstream water quality to assess the agricultural stock watering and irrigation use and use of Utah Lake water in secondary irrigation systems. Recommendations for this section include:

- Develop methods for assessing support of downstream uses and an approach for data collection
- Determine water quality requirements for ELS of Utah Lake aquatic wildlife and assess conditions to determine use support.

10.3 Water Quality Model Development

The University of Utah is currently developing a suite of watershed and in-lake water quality models to predict water quality conditions in Utah Lake. DWQ anticipates that this model suite will serve as one of the primary tools to predict and simulate nutrients in the lake. At the time of this writing, the U of U intends to deliver a calibrated modeling suite to DWQ for application to the ULWQS in December 2018. Recommendations for the model development task include:

- Support of ongoing data collection to support model development including data collection for the EFDC circulation model
- Integrate the U of U modeling team with the ULWQS Science Panel
- Develop sensitivity analyses to help prioritize future research and data collection.

10.4 Utah Lake Loading Analysis

The existing Utah Lake water budgets and loading analyses provide good estimates of water quantity and TP loading delivered to the lake. However, there are some limitations and data gaps to be addressed. First, the water budget was developed using average monthly flow values, which will result in mischaracterization of load delivery during significant hydrologic events like runoff, precipitation, and water management activities. Additionally, these load analyses do not include loading estimates for nitrogen parameters. It is anticipated that the water budget and load delivery estimates will be improved as a result of the U of U modeling effort. The recommendations for this section are discussed to support model development and calibration:

- Identify and monitor ungaged inflows to the lake
- Develop and maintain a continuous flow monitoring network to support calibration of a water budget
- Continue investigation of direct drainages and influence on lake loading
- Continue monitoring tributary and direct drainages for further characterize nutrient and water inputs to the lake.

10.5 Watershed Source Analysis

A detailed watershed source allocation is planned for Phase 3 of the ULWQS where loading will be characterized for each significant source and contribution area. During Phase 3 load estimates will be developed for each source including natural background, forest management practices, range management practices, stormwater, agricultural sources, POTWs, and others. This differs from the scope of Phase 2 to characterize the total load delivered to the lake. It is likely necessary to develop watershed-scale models to complete a watershed source analysis. Recognizing that the ongoing modeling effort is constructing a series of watershed models, it is recommended to first evaluate these for applicability to watershed source characterization. Additional recommendations include:

- Implement a stormwater monitoring network to characterize stormwater quality for a variety of urban land use compositions
- Stormwater monitoring
- Data collection to support U of U model development
- Evaluate capabilities of U of U watershed models for application of future load allocations
- Identify and evaluate significance of agricultural returns flows and drainages
- Develop and maintain a continuous flow monitoring network to assist in model calibration and identification of significant hydrologic events
- Further develop the watershed loading metadata analysis to inform a watershed-scale monitoring effort to support load allocations.

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12 Appendix A – Utah Lake Bibliography

13 Response to Comments

Commenter	Comment	Response
Mitch Hogsett	Why are the dissolved parameters of ammonia and nitrate parameters presented in Table 6 as non-filtered parameters.	Both the filtered and unfiltered fraction for these parameters are analyzed and presented in the table. Both fractions are analyzed to understand the complete nutrient speciation within the sample.
Michael Brett	At the August 8, 2018 Science Panel meeting, the Panel requested clarification on the methods employed by the Utah Public Health Lab (UPHL) for analysis of total phosphorus. Specifically, do the lab analytical methods appropriately account for turbidity interferences to minimize over estimation of total phosphorus concentrations	Based on the Utah Public Health Laboratory (UPHL) Standard Operating Procedure (SOP) for TP analysis and EPA method 365.1 sediment /turbidity interference is appropriately minimized. Total P (Unfiltered; TP) and Dissolved P (filtered [<0.45um]; DP) are analyzed after acidic persulfate digestion. The digest may be performed offline using an autoclave, or inline (within a rapid-flow or segmented-flow analyzer), or both. The persulfate mineralizes all organic-P to orthophosphate, while the acidic background of the digest will mineralize polyphosphates and dissolve / desorb Ca-P and Fe-P minerals (at reasonable concentrations for fresh surface waters; this test is not set up for industrial wastes, per se.) Second, UPHL homogenizes the samples prior to collection of an aliquot for the digest procedure, so underestimation should not be an issue. Third, these analyses (quantitation) are run on a continuous-flow-analysis colorimetric system w/ an auto-analyzer, such that digested samples run through the required reagents (and mixed, heated, etc.) in-line prior to detection.
Michael Brett	The phytoplankton analysis should be enhanced to include total phytoplankton biovolume in addition to relative abundance and some analysis of seasonal succession.	The Utah Lake Data Explorer tool was revised to present biovolume and seasonal succession of individual phytoplankton division and genera.
Theron Miller	“Poor scientific sampling”	This comment was provided in a PDF version of the Phase 1 report and it was unclear which section, page, or graph it is referring to. Additional clarification was requested but not received. No edits were made in response.
Theron Miller	“Need to explain that cell counts are not part of EPA's criteria. Also most of these exceedences were beach surface scum samples.”	The usage and sources of multiple assessment indicators for harmful algal bloom assessment are fully described in the 2016 Integrated Report (https://deq.utah.gov/legacy/programs/water-quality/monitoring-reporting/assessment/2016-integrated-report.htm), and a full discussion of the usage of cell counts versus cyanotoxin concentrations for water quality assessment is available in the 2016 Integrated Report response to comments (Appendix A, section 2, https://deq.utah.gov/legacy/programs/water-quality/monitoring-reporting/assessment/docs/2016/dwq-response-to-public-comments-final2016ir-v2-1.pdf). Although there are several potential means for assessing water quality impairments resulting from HAB occurrence, based on the rationale described in those two documents, DWQ has concluded that the use of cyanobacterial cell counts as a recreational use assessment indicator is scientifically defensible and appropriate. The different types of samples used here and in the 2016 Integrated Report are described in section 6.6.2 of this document. Exceedances of DWQ’s cyanobacteria cell count assessment threshold were observed in both surface and composited phytoplankton samples at both beach and open water site locations in 2016. Exceedances have also been observed in multiple sample and location types in Utah Lake in subsequent monitoring. No edits were made in response to this comment.
Theron Miller	“Figure 7 nd Table 12 misrepresent actual chronic criteria. These are instantaneous grab samples and not 30-day average measurements”	Figure 7 is a comparison of observed ammonia concentrations among sites and does not reference any ammonia criterion. Table 12 compares the ammonia grab samples to all potentially applicable criteria. This approach is clearly documented in the text and is consistent with assessment methods used in the Integrated Report. It is unclear from the comment why the commenter believes that comparison of sample results to chronic criteria and the calculation of exceedance frequencies is a misrepresentation of chronic criteria. The intent of assessment is to identify a variety of potential water quality issues including the occurrence of both acute and chronic criterion exceedances. As such, comparisons of data against all

Commenter	Comment	Response
		applicable criteria are made, and exceedance frequencies are used to characterize the likelihood of exceeding various criteria. If high enough frequency data are collected to differentiate between instantaneous and 30 day average ammonia concentrations in Utah Lake, this analysis could be revisited. However, given the occurrence of acute criterion exceedances at the impaired site, this is unlikely to impact the overall assessment. The text and table have been updated to specify that the chronic criterion means the 30 day criterion.